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Soil Treatments for the Control of Diseases in the Greenhouse and the Seedbed

A. G. Newhall and Charles Crupp

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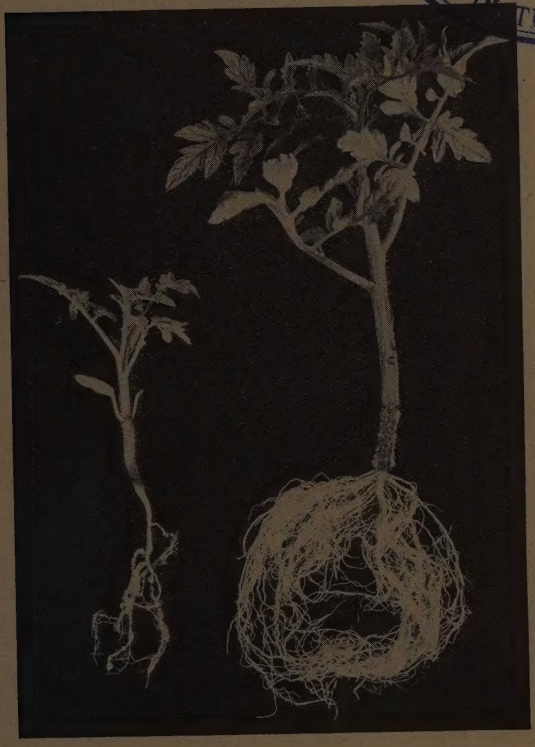

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SOIL TREATMENTS FOR THE CONTROL OF DISEASES IN THE GREENHOUSE AND THE SEEDBED

A. G. Newhall and Charles Chupp

Any grower who makes use of greenhouse soil, hotbeds, or outdoor seedbeds will sooner or later have trouble with soil organisms that injure his crops. Some of these troubles can be eliminated by the easy process of crop rotation, fallowing, or planting resistant varieties, but most of them are so difficult to avoid that the only means left is that of soil sterilization.[1] This is a rather expensive control measure that is applicable only to limited areas and under conditions that really require drastic measures.

REASONS FOR SOIL STERILIZATION

The most important reason for soil sterilization is the killing of disease-producing fungi and bacteria in the soil. The number of such organisms is far too great to include any account of their life history in a bulletin of this kind. The mentioning of the most common ones, however, will suffice in drawing attention to the seriousness of the problem. Probably the first in rank is the almost ever-present Rhizoctonia. It is the principal cause of damping-off, or blackroot, and of wire-stem, and produces bottom-rot of lettuce and various stem rots. It is difficult to say which organism is second in destructiveness. *Sclerotinia sclerotiorum* and other closely related species of Sclerotinia, also cause damping-off and stem rots, as well as drop of lettuce and rots of bulbs, roots, and fruits. Pythium, Aphanomyces, and other lower forms of fungi frequently are the cause of damping-off and root rots of various types. There are many species of soil Phytophthoras, all of which seem to be virulent parasites that cause damping-off and stem and fruit rots. *Thielavia basicola* is the fungus connected with the black root rot of sweet peas, sweet violets, and many other plants. *Sclerotium rolfsii* is present only in the South but there has a wide host range. Verticillium is almost as widespread as Rhizoctonia, and frequently does an immense amount of damage on many

[1] Because of its more general usage in the past, the term *sterilization* has been retained in this bulletin, although it is well understood that it is not quite accurate since all of the micro-organisms in the soil are rarely if ever killed by the treatments mentioned herein. At best only partial sterilization is accomplished. The term *disinfection* would convey the proper meaning to most readers, but unfortunately is just as inaccurate, because strictly speaking only animate objects can become infected, others being merely contaminated. *Pasteurization* in its present usage applies only to liquids. Perhaps the most accurate term would be *disinfestation* were it not for its entomological implications.

crops both indoors and in the field. *Plasmodiophora brassicae,* causing club-root, is very limited in its choice of hosts, as it affects only plants belonging to the cabbage or crucifer family but, on them, it may cause considerable loss. The species of soil Fusaria are extremely numerous, and many of them are destructive pathogenes on cultivated plants. *Bacterium tumefaciens,* the cause of crown gall, is present in a limited manner on many crops, and sometimes may become destructive. Botrytis, producing the gray mold of vegetables, is very common and is destructive when the moisture and the temperature are favorable for its growth. Soil that contains vegetable refuse may harbor the soft-rot bacterium, *Bacillus carotovorus,* which attacks many varieties of plants both in the greenhouse and the field. Among other organisms that may be present in the greenhouse soil are *Actinomyces scabies* (common potato scab), *Bacterium campestre* (black-rot of crucifers), *Bacterium solanacearum* (brown-rot), *Cladosporium cucumerinum* (cucumber scab), Colletotrichum and Gloeosporium (anthracnose) of various species, and *Phoma lingam* (black-leg of crucifers). Recent investigation has shown that the virus of certain mosaic diseases can remain in the soil for several months, and that only soil sterilization can control the trouble if one susceptible crop follows another closely.

Even though such a large number of plant pathogenes are present in the soil, the average grower sterilizes but for one thing, and that is the eradication of the nematode, or eelworm, (*Heterodera radicicola*).[2] It occurs all over the world where cultivated plants are grown. In the South it lives in the open field, but in New York State it is confined almost wholly to the greenhouse. Very few greenhouses are completely free of it, and in many of them it causes almost total losses of cucumbers and tomatoes. Its host range is so very wide that other crops may be equally injured by this pest.

Other benefits are to be derived from soil sterilization in addition to that of killing disease-producing organisms. The killing of the weed seeds in a seedbed is almost as important. All weeds that come up in such beds must be pulled by hand, so that the labor not only is costly but the removal of the undesirable plants frequently causes root injury of the delicate seedlings which need protection. Aside from the advantage of weed eradication, some types of soil are made more friable by steam sterilization and may not become water-logged so easily. Still another minor benefit may be the greater amounts of soluble nitrogen and phosphorus in sterilized than in unsterilized soils that may stimulate plant growth.

[2] = *Caconema radicicola.*

In any greenhouse that has been used for a number of years, there are sure to be many insects that feed upon plant life. Being protected from low temperatures, some of these can multiply much faster than they do in the field. Eggs, cocoons, or larvae may be harbored under boards or other material in the house, and thus remain unseen. When the soil is sterilized, either the heat or the fumes of the chemicals will kill many of the forms, so that insect life should not be so abundant in regularly sterilized houses as in those which are neglected.

PRECAUTIONS NECESSARY

Those men who have tried soil sterilization for the first time have not always been successful in the operation. The trouble is that certain definite precautions are necessary, and when one of them is neglected, the entire procedure may become valueless. The first precaution is that the operation be done thoroughly. If steam is used, the pressure should be great enough, the volume sufficient, and the time of exposure long enough to heat the soil to the proper depth to kill the parasitic organisms. If a chemical is applied, it should be one specifically recommended by an experiment station for the particular pests involved. Then enough of the material should be mixed with the soil to bring about the desired results.

The second precaution is vigilance against recontamination with the parasitic microorganisms. In order to act intelligently on this point, one must be fairly familiar with the plant and animal life in the soil. Of course the nonparasitic and helpful ones are soon introduced again on dust particles, in the hose water from above, and the capillary water from below, and sometimes in the fertilizer used. The number of organisms in even a thimbleful of surface soil is unbelievably large.

The parasitic organisms can gain entrance again in numerous ways. They may be washed in from the unsterilized boards surrounding the bed or from the untreated paths between the beds. Another source of recontamination is the workman who walks over unsterilized soil and then, with particles of this clinging to his footwear, steps on the sterilized beds. When the beds are so large that the workman must walk over them, it would be well for him to have special footwear for that particular job so that, if there is any chance of carrying contamination, the shoe soles or boots may be dipped in a rather strong solution of formaldehyde (5 per cent or more).

There is little use in sterilizing soil and then watering it with surface water from shallow wells or ponds into which all kinds of parasitic organisms may be washed. Water from deep wells or from city hydrants usually is free from contamination and may safely be used. Even water

from a shallow well is safe if no surface water can flow into it. Private ponds should be disinfected with copper sulfate (1 pound in 10,000 gallons) if there is reason to believe they are contaminated.

Sometimes hotbeds or cold frames are built near the base of a hill, so that, with each washing rain, contaminated soil is washed down or the surface water from such soil enters the beds and thereby defeats the purpose of sterilization. In level country where there is loose soil, heavy winds may cause enough drifting to induce recontamination.

Any barnyard manure or additional humus that the soil requires should be applied before the process of sterilization is started, for soil pathogenes frequently are introduced by means of such foreign matter. In some places it is the practice to furrow the beds, drop the seed, and then cover it with pure sand. In such cases it is just as necessary to sterilize the sand as the remainder of the bed. In addition, the seeds should be disinfected, either with mercury compounds, with hot water, or by any other safe and efficient method. Many of our most serious parasites of plants are carried on the seed.

The third precaution is that the machinery and the soil be in the right condition for conducting the work most expeditiously. For instance, it is stated that from three to four times as much heat energy is required to raise the temperature of a pound of water to a given degree as is required to raise the temperature of the same weight of dry soil. Consquently, if soil is very wet, and this applies more to clay soils than to sandy ones, it is much more difficult to heat it sufficiently for the purposes in hand, or if chemicals are used, the extra water may so dilute the fungicide that it will be of less value.

During the winter there may be more time for sterilizing the soil than during the rush of spring and fall work, but there is one serious objection to doing it then,—neither chemicals nor heat will penetrate frozen ground. There is also reason to believe that at temperatures below 50° F. the efficiency of chemicals is much reduced. The soil should be loose, not too wet if clay, and in good tilth. A fertile soil will recover more quickly from harmful effects of sterilizing than will a poor one. In addition, a grower can afford such an expensive operation as sterilizing only on good soil that will later yield a maximum crop.

POSSIBLE ILL EFFECTS FROM SOIL STERILIZATION

Growers sometimes remark that the soil is "dead" for a time after sterilization. They mean that seeds will not germinate nor plants grow well for a brief time after steam or chemicals have been applied. Much has been written on this subject in an attempt to explain why some soils react in this manner, and some very ingenious theories have been

advanced, as well as others that are very practical. Thus, it has been said that protozoa—low forms of animal life—are not killed so readily as bacteria and, as the protozoa feed on the bacteria, they kill the few remaining beneficial individuals left in the treated soil. Other statements are that some poison or toxin is liberated in the soil and that these react on the plants grown there. But if some time, of variable duration in the different cases, elapses between the period of sterilization and of planting, and if the soil is sprinkled at intervals, the toxin will be leached out. The nature of the toxin seems not to be settled definitely, but a number of the research men mention ammonium or sodium salts as possibilities. Still others reason that the presence of a toxin is not necessary to explain the poor growth of plants or the lack of germination in the seed. If there are enough soluble salts in the soil, they will hinder growth as surely as will the presence of a single active poison.

One difficulty that growers have with steam-sterilized soil is that at first the regular watering is not sufficient and the young plants may be stunted from lack of moisture. After steaming, certain soils are so changed temporarily that capillary moisture will not rise so quickly as before from the lower layers, and when the top layer becomes dry, no other water is available until it is applied on the surface. This ill effect, however, is temporary, like all the others connected with sterilization, so that if seeds are not planted for a week or ten days after the treatment, the soil usually will have had time to become normal again.

In both steam and chemical applications puddling may take place if proper care is not taken to avoid it. In steam sterilization the pressure and temperature should be high enough to avoid the condensing of the steam too quickly, otherwise it will penetrate the soil as water, and puddling will result. The dryer and looser the soil, the less danger there is from this. In the case of chemicals that are applied as a solution in amounts ranging from ½ to 1 gallon to 1 square foot, puddling may take place if the solution is all poured on at once and left to stand on top of the ground. It is better to apply part of the material, and when the soil seems to have absorbed that, to pour on the remainder, or to divide the application into as many divisions as seem required by the special type of soil under consideration.

Two minor troubles are sometimes met with in soil sterilization. So much nitrogen may be made available by the treatment that the plants grow in too succulent a manner. Tomatoes and cucumbers, for instance, may grow all to vine and bear small or undesirable fruit. Fortunately this is very rare, and in most cases the harvest will be greater in the sterilized than in the unsterilized soil even though no diseases are present in either. The second trouble is the fact that steam-sterilized seedbeds

may be slightly more acid than are the untreated beds. This may be a disadvantage in a bed that is inclined normally to be rather acid. But experience with growers would indicate that they err much more often on the side of too great alkalinity, so that sterilizing should be an advantage in their case instead of a hindrance.

TIME AND FREQUENCY OF STERILIZATION

It often happens that a greenhouse man will suddenly have an almost entire loss of his crop due to certain diseases. At once he is anxious to sterilize the soil but does not have any apparatus for conducting such a practice, and to his sorrow finds that it takes him so long to assemble the various parts or materials that it is time to plant another crop before he is ready. The moral, obviously, is that when a new greenhouse is being built, soil sterilization should be kept in mind, and the materials and the apparatus procured for the time of emergency. If he expects to use steam for the control of nematodes or fungi, he should see that the steam pipes are so arranged that steam outlets are available at any place needed, that steam-pans, conducting pipes, or tile—depending upon which he cares to employ—are either in place or available for immediate use. If he does not have steam pressure in his own greenhouse, he should make an attempt to locate a portable boiler that would serve the purpose, and which he could rent or buy when the occasion demanded it.

If chemicals are to be used, a place of purchase should be located long before they are needed. Money might be saved if local dealers were canvassed for prices and quality of material. In addition, the grower would do well to obtain the names of wholesale chemists, and procure price lists from them. Often local dealers do not handle materials of this kind, and certain wholesale chemists may carry one kind of material but not another.

Furthermore, a quick and simple method of applying the chemicals should be devised. If large quantities of such solutions as formaldehyde or acetic acid are to be applied, it would be well to build an overhead tank sufficiently large to hold enough solution for an entire bed or house, and from which the solution would flow by gravity through a rubber hose.

The question of the time of year to sterilize the soil presents a problem to many growers. In some establishments crops follow one another so closely that there seems no time between rotations; in others the harvesting of outdoor crops interferes with sterilizing at the correct time so that, in many cases, this very important control measure is delayed from year to year or neglected entirely. If, however, the practice is kept in

mind a year ahead, plans can be made to do the work between crops and when outdoor duties are not too pressing.

If the sterilizing is well done, so that all of the pathogenic organisms are killed, the same soil does not always have to be sterilized every year. In fact, it is a good practice to do the work so well that it need be repeated only every two or three years. Too much sterilizing may not be beneficial, especially on some soils. It is true, however, that some men prefer a slight sterilization twice a year to one prolonged or intensive application at less frequent intervals.

STERILIZING WITH HEAT

In spite of many years of testing chemicals for soil sterilization nothing is so universally effective against all soil-harbored pests as heat. Heat is also transient. It can be applied any number of times without building up an accumulation of detrimental residues. Furthermore, it lacks the elements of danger and of disagreeable irritation which some chemicals possess. Therefore, wherever possible, some form of soil heating should be considered first in any program of eradicating soil pests.

STEAM STERILIZATION

Wherever boilers are available steam will probably give the most satisfactory results. Its use is adapted particularly to large greenhouses equipped with steam heat, also to out-of-door seedbeds if a portable boiler is available. There are several methods of steaming, each taking its name from the more or less special apparatus it requires. Under certain conditions one may be distinctly better suited than another. The principal ones considered in this bulletin are the buried-tile method, the buried-perforated-pipe method, the inverted-pan method, the steam harrow or rake method, and the English steam bins.

When the so-called high-temperature crops, such as tomatoes and cucumbers, are grown in the greenhouse in rotation, either the buried-tile or the perforated-pipe method of sterilizing is the most convenient and satisfactory way of holding nematodes (*Heterodera radicicola*) and *Fusarium* or *Verticillium* wilts in check, because deep sterilization is required to control these organisms. These pests may penetrate to the second and third foot below the surface. When soil temperatures remain high, they quickly find their way back into the surface layers if a shallow job of steaming has been done. With such crops, however, as radishes, lettuce, and spinach, grown at lower temperatures, it is not so necessary to sterilize deeply (more than 9 inches). The pan or even the steam rake may be satisfactory under these circumstances, although the latter is very inefficient in the hands of most men in fighting either

nematodes or Fusarium wilts and so is no longer generally recommended. The chief objection to the buried-tile method is the cost of installation. With the buried-pipe method, the principal objection is the great labor required each year to bury and dig up the pipes. The objections to the other methods are that they are much less efficient and too slow where small units are employed.

The buried-tile method

The buried-tile method is now gaining the greatest popularity among greenhouse men throughout the Northern States, not alone on account of its efficiency but because the buried lines of tile may be used for sub-irrigation and for carrying off undesirable, excess soluble salts from the soil. It consists of a series of trenches from 13 to 16 inches deep and 18 inches apart in which ordinary 3- or 4-inch clay drain tiles are closely laid end to end as for drainage purposes and thru which live steam is passed. The far ends of the lines of tile are cross-connected with more tile. The near ends are supplied with steam through a "cross header" pipe having a series of nipples, one leading into each row of tile (figures 1 to 7). One header may feed from four to forty lines of tile at a time, but the length of the lines should not be more than from 75 to 100 feet for best results, and the total area fed by one header should not exceed the capacity of the boiler. A 100-horse-power boiler can take care of a unit area, fed by one or two headers, of 600 to 1200 square feet. By such an arrangement one can raise the temperature of the soil to at least 160° F. to a depth of 15 to 20 inches in three to six hours of continuous steaming. Sterilization is accomplished by the steam which escapes under pressure at the joints between the tiles. Perforated tiles have been tried but seem to have no special value, for there is enough of a crack between the ends even when they are laid as close as possible.

A certain amount of leeway is permissible in many of the details of a buried-tile installation; for example, 4-inch tiles may be used in place of the 3-inch. The much greater joint area enables 4-inch tiles to function even after considerable displacement. In very large greenhouses where steam pressures of 100 pounds or more are maintained at the headers, the smaller tile may be split open by the sudden admission of too much steam.

Likewise, the proper distance to space the lines apart may vary for different soils and different depths of the trenches. While 18 or 19 inches, center to center, is probably the best in a majority of cases, successful installations have been made with the lines as far apart as 22 inches and as close as 15 inches. Greater distances than these result in slow and inefficient steaming, while closer ones are too expensive to install. The

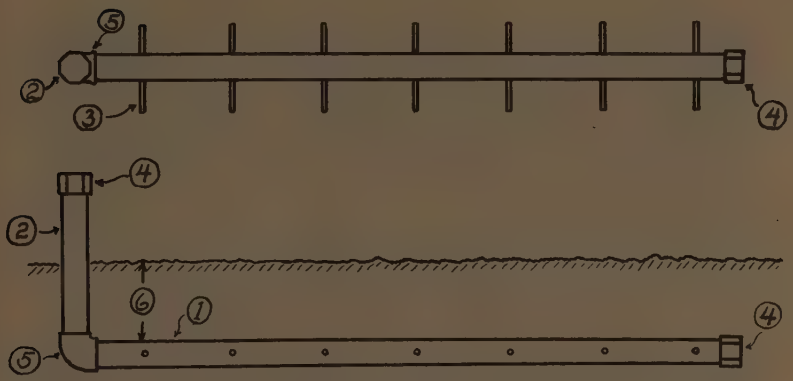

FIGURE 1. DETAILS OF A HEADER DESIGNED TO DELIVER STEAM IN OPPOSITE DIRECTION TO SEVEN LINES OF TILE

1, Galvanized wrought-iron pipe, tapped at 18-inch intervals for ¼-inch nipples. 2, A riser 18 to 24 inches long provided with a union to attach a steam line to and a cap when not in use. 3, Six-inch nipples of ½-inch pipe screwed into header. 4, Caps. 5, Elbow. 6, Depth below surface of ground beds 8 to 12 inches, less in bench soil. Refer also to figures 2, 6, and 7

COURTESY OF THE HANCOCK BRICK AND TILE COMPANY

FIGURE 2. A SHORT HEADER IN PLACE

This header feeds four lines of tile in both directions. The nipples leading from the header into the "header tile" do not show. Headers may be placed at the ends of the beds to deliver steam only in one direction (figure 7)

COURTESY OF THE OHIO AGRICULTURAL EXPERIMENT STATION

FIGURE 3. TILED GROUND BEDS DEVOTED TO ORNAMENTALS

The lines are 8 inches below the surface and are 22 inches apart, which is a little too far apart for this shallow depth. The leads and headers are of 1¼-inch pipe. The beds are 7 by 45 feet in size and require from six to nine hours of steaming

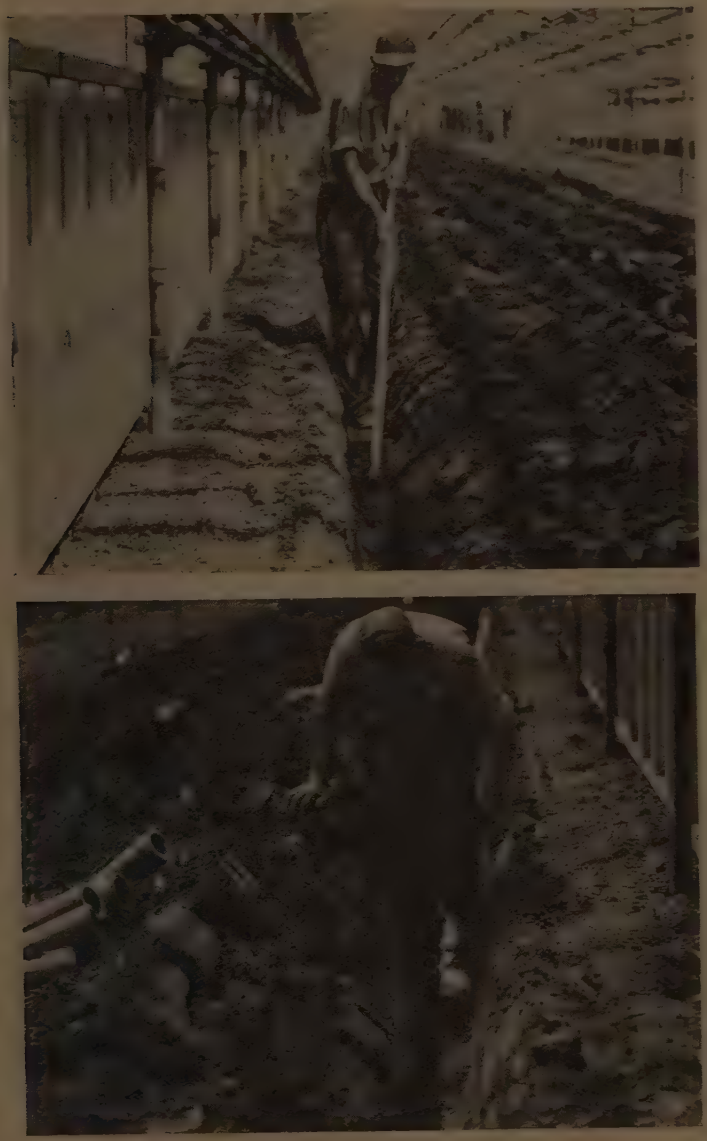

FIGURE 4. THE TRENCH

After a deep furrow has been made, the trench is completed by hand. A thin layer of cinders or crushed stone is then spread in the bottom, and the tiles are carefully laid, end to end, as close as they will fit

depth of the tiles below the surface should be just great enough to enable the soil to be plowed without danger of their displacement or breakage. This will call for a clearance of at least 8 inches above the tiles.

As indicated, much leeway is permissible in the shape and the size of a unit area to be fed by one header or steamed at one time. There are many installations where from 3 to 11 square feet per boiler horse power are steamed at one time. Two boilers of the same rated horse power may differ much in their actual capacity. Firemen also differ in their capability.

The longevity of a permanent tile system varies somewhat with the kind of soil and the care used in laying the lines. The oldest installation known to the authors has been serving its owners for eighteen years but is in need of resetting. Several installations have been in service for twelve to fifteen years, although some of these have been reset for one reason or another recently.

A diagram of a layout suitable for a small range composed of separate greenhouses 30 feet wide by 180 feet long is shown in figure 5. Assuming there is a 100-horse-power boiler, each unit is arranged to cover 750 square feet, so that one house can be steamed with only eight units, or changes. With lines 18 inches apart, a house 30 feet wide permits the laying of twenty parallel lines. Five lines 100 feet long constitute one unit and are fed by one header. Ten lines 50 feet long can be steamed, but this requires the use of twice as many headers, an unnecessary expense. The headers are of 2- to 3-inch galvanized wrought-iron pipe and are tapped for five pairs of ½-inch nipples 6 inches long, through which the steam is admitted into each line of tile in opposite directions. The blind end of the header is capped, while at the opposite end there is

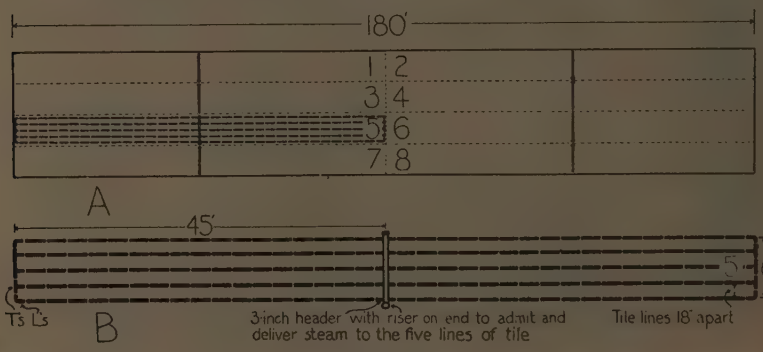

FIGURE 5. GROUND PLAN OF A BURIED-TILE INSTALLATION FOR A SMALL HOUSE 30 BY 180 FEET

A, The arrangement of eight separate tile units, 7½ feet wide by 90 feet long, each containing 275 square feet. B, One unit of A enlarged to show details of construction and connections

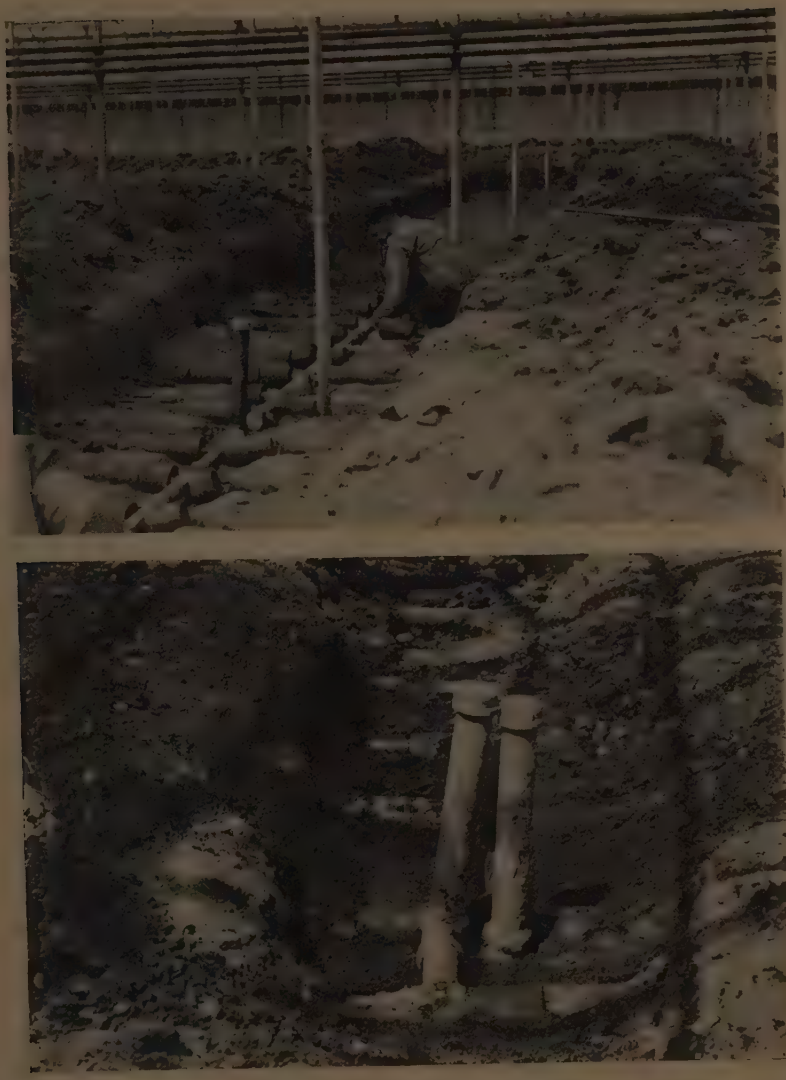

FIGURE 6. INSTALLATION OF HEADERS

Upper: Laying the headers and fitting the tile over the nipples. Each header feeds ten lines in this installation. Lower: Two capped 2-inch risers are all that will show aboveground after the headers are installed and the soil is leveled

an elbow and a riser to which the steam supply line is connected (figures 1, 2, and 6). The upper end of the riser protrudes 1 foot above the ground and is capped when not in use. If in the way when the bed is cultivated, the riser may be removed and a plug substituted. The header tiles are specially constructed to fit the 6-inch nipples snuggly (figure 7). Tile

FIGURE 7. BENCHES STEAMED BY THE BURIED-TILE METHOD

One line of tile instead of four, as pictured, may be steamed at a time if the boiler capacity is limited. The tiles are removed as soon as they are cool enough to handle

may be bought for this purpose or they can be made from an ordinary tile with a little cement. The far, or blind, ends of all tile lines, as stated before, should be cross-connected to permit better circulation of steam in case a line becomes clogged. Tees and ells and fractional lengths of tile may be bought for this purpose.

Some men installing lines in heavy clay soil have spread a thin layer of cinders, crushed limestone, or sifted pebbles under the tiles and around the joints to reduce the chances of clogging at the joints. But whether the practice is of much value or not remains to be demonstrated.

When tiles are to be employed for leaching out excess soluble salts from the soil, it is essential that one or more lines be connected with an outside drain. This must be tightly closed off, of course, during the pro-

When there is a marked slope to the ground, it is best to place the header at the upper end of the lines, to permit the flow of the condensed steam away from the nipples. Otherwise pounding and local puddling may occur and result in dislodging the first 2 or 3 tiles. In such cases the headers will all have to deliver steam in just one direction

Cost of tiling an acre of greenhouse [3]

Installing the tiles and the necessary permanent mains, leads, valves, and headers is an expense which varies with the distance apart of the tile lines, the type of soil, and the quality and quantity of the steam fittings. Usually the entire job can be done for $1800 to $2800 an acre, which is between 4 and 6½ cents a square foot. For example, in ordinary loam soil one man can lay from 450 to 550 tiles 8 inches deep (to their tops) in a ten-hour day, which at $4 a day is nearly 1 cent a tile. On an acre, tile lines 18 inches apart will require approximately 29,500 tiles, at a cost of nearly $750 plus $300 for laying. If unit areas of 700 square feet are fed from each permanent header, about sixty of these will be required, which at approximately $10 apiece will be another $600 for headers and their valves. The necessary steam pipes for mains and leads, a number of valves of different sizes, and the labor for installation can easily add another $1000, bringing the total to $2650 an acre of 43,500 square feet. A saving in cost may be made on the last two items. For example, by using larger unit areas calling for fewer headers and valves, by making the headers at home in spare time, and by using mains and leads already installed for heating purposes, the cost may be considerably reduced.

The interest at 6 per cent on an investment of $1800 to $2800 is from $108 to $168. This must be added to the annual charge for approximately 70 tons of fuel to the acre (at $5 = $350). This last charge is very nearly the same for all types of steam sterilization, so in comparing the cost of steaming by the tile method with that by the other methods the chief items to consider are the interest on the investment in the tile method and the labor bills in the other methods. Some owners claim they would rather keep their help at work the year round, and so are glad to employ them during the slack season at one of the more laborious methods of steam sterilizing, such as the buried-perforated-pipe or the inverted-pan method.

Coverings for the soil

It is wise to cover the area being steamed with something to confine the heat and provide insulation. For this purpose heavy building or mulching paper has proved very satisfactory. It is a good insulator, is

[3] All cost items have been much reduced since the figures in this bulletin were obtained (1928–30).

easily rolled and suited to long narrow beds, can be used many times, and is not too expensive. Papers impregnated with tar or creosote products are apt to be toxic to some plants and should not be used. Canvas is very commonly used (figures 3, 8, 12, and 13), and tarpaulins, old carpets, boards, or even burlap sacks have also given more or less satisfactory

FIGURE 8. A CANVAS COVER FOR THE SOIL

Canvas makes a very suitable covering which will help to confine the heat. Refer also to figures 3, 10, and 12

results. In any case it is wise to leave the covering on for a few hours after the steam has been turned off, to confine the heat that much longer.

Size of steam conductors

It is essential to provide pipes of adequate size throughout, for the quantity of steam delivered to the soil is limited to that which can pass through the smallest pipe in the system. Recent one-acre greenhouse installations have been made employing 4-inch mains with 3-inch leads and headers throughout (figures 9 and 10). Since at 75 pounds pressure a 2-inch pipe will pass but 19 pounds of steam per minute (table 1), while a 3-inch pipe can pass 42 pounds and a 4-inch pipe 72 pounds, it is evident that the larger sizes should be used. Furthermore, the pressure drop in pounds per 100 feet of pipe is much greater in the smaller sizes of pipe, such as 1- or 1½-inch (table 2), hence these are less satisfactory for long leads in larger installations.

TABLE 1. FLOW OF STEAM IN POUNDS PER MINUTE THROUGH STANDARD PIPES (Velocity 4000 feet per minute)*

Pipe size (inches)	Gauge pressure in pounds per square inch — standard pipe							
	10	15	25	35	50	75	100	125
1	1.47	1.74	2.28	2.82	3.61	4.91	6.18	7.45
1½	3.47	4.11	5.38	6.65	8.50	11.57	14.46	17.56
2	5.72	6.78	8.88	10.96	14.02	19.06	24.02	28.92
2½	8.16	9.68	12.68	15.64	20.00	27.20	34.26	41.28
3	12.60	14.93	19.57	24.13	30.85	42.00	52.88	63.70
4	21.70	25.73	33.70	41.58	53.15	72.33	91.10	109.80

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FIGURE 9. STEAM MAINS AND LEADS

The mains and leads should be large enough to make the best use of the boiler capacity. These 2-inch leads take steam from a 3-inch main. Each lead supplies one 12-foot, underground header which steams an area of 1800 square feet in eight hours

FIGURE 10. A THREE-ACRE HOUSE IN WHICH 4-INCH MAINS (A) SUPPLY 3-INCH LEADS (B) WHICH FEED 2-INCH HEADERS UNDERGROUND

TABLE 2. PRESSURE-DROP IN POUNDS PER 100 FEET EQUIVALENT LENGTH (Velocity 4000 feet per minute)*

Pipe size (inches)	Gauge pressure in pounds per square inch — standard pipe							
	10	15	25	35	50	75	100	125
1	1.51	1.91	2.49	3.09	3.96	5.38	6.77	8.16
1½	0.77	0.91	1.19	1.47	1.88	2.56	3.22	3.89
2	0.50	0.60	0.78	0.98	1.24	1.69	2.16	2.56
2½	0.38	0.45	0.59	0.71	0.93	1.27	1.60	1.93
3	0.27	0.32	0.42	0.52	0.66	0.90	1.14	1.37
4	0.18	0.21	0.27	0.34	0.44	0.60	0.75	0.91

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High- or low-pressure steam

There is considerable misconception about the relative merit of high-pressure steam over low-pressure steam. It is often said that high-pressure steam is drier steam and hence less apt to cause puddling of the soil. As a matter of fact it is not drier steam, for it actually contains more moisture per cubic foot than does low-pressure steam. It does cause less puddling, however, because it carries more heat and raises the soil to the desired temperature before much condensation takes place. For example, at 20 pounds pressure steam has the temperature of 259° F., while at 80 pounds its temperature is 324° F. (table 3). Expressed in heat units

TABLE 3. TEMPERATURE, VOLUME, WEIGHT, AND HEAT OF STEAM AT DIFFERENT GAUGE PRESSURES

Gauge pressure (pounds)	Temperature of steam (degrees Fahrenheit)	Specific volume per pound (cubic feet)	Weight per cubic feet (pounds)	Total heat in 1 pound of steam, above 32° F. (British thermal units)
2	219	23.57	0.042	1,153
5	227	20.44	0.048	1,155
10	239	16.60	0.060	1,160
20	259	11.95	0.087	1,166
30	274	9.46	0.105	1,171
40	287	7.79	0.128	1,175
50	298	6.65	0.150	1,178
60	307	5.86	0.170	1,181
70	316	5.19	0.192	1,183
80	324	4.66	0.212	1,185
90	331	4.25	0.235	1,187
100	338	3.88	0.257	1,188
120	350	3.34	0.295	1,191

delivered to the soil, a 3-inch pipe will pass 12.6 pounds of steam per minute at 10 pounds pressure, carrying 14,616 British thermal units (B. T. U.), or heat units. The same pipe will deliver 30.85 pounds per minute at 50 pounds pressure, carrying 36,341 British thermal units. Hence more than twice the heat is delivered to the soil in an hour of steaming with the higher pressure. The soil can be raised to the same temperature with the low-pressure steam, but in the extra time required the soil is able to absorb a greater proportion of the moisture contained in the steam and so is wetter in the end. It is therefore more imperative that soil be loose and dry if low pressures are to be employed.

Since it is the heat units actually delivered to the soil that determine the efficiency of the job, it is more important to know the pressure at the header that at the boiler. By placing a pressure gauge at or near the header and referring to the tables, one can tell how long to steam each location in order to deliver the same heat to each one. It soon is evident why locations a considerable distance from the boiler require longer steaming than locations close to it.

It should not be inferred from the preceding discussion that it is useless to try to steam soil with a low-pressure boiler. Fairly good results can be obtained with a boiler pressure of 15 pounds if enough time is allowed and if the soil is dry and thoroughly loosened or pulverized. More care must be used to free the lines of all condensation water before turning the steam into the soil (figure 14).

The buried-perforated-pipe method

Although the buried-pipe method is essentially like the tile method, it differs in two ways: It requires much more labor to set the pipes in the ground and remove them every few hours; and smaller unit areas are steamed at a time, so shorter periods of steaming (one to two and one-half hours) are required with the same boiler capacity. Besides the extra labor, obviously the advantages of subirrigation and leaching possessed by the buried-tile-method are lost. However, the first costs for materials and installation of the buried-perforated-pipe method, are comparatively low, and the efficiency of this method compares very favorably with that of the tile method, temperatures of 160° F. being obtained at depths of 9 to 15 inches in one or two hours.

Considerable leeway is permissible in the specifications of a successful pipe installation. The pipes should be from 1¼ to 2 inches in diameter and may be from 20 to 120 feet long. Holes ⅛ to 3/16 inch in diameter are bored at 8- to 16-inch intervals, and for the best results should be staggered in two or three rows on one side of the line. This side becomes the bottom of the pipe as laid in position (figure 11). It is customary to

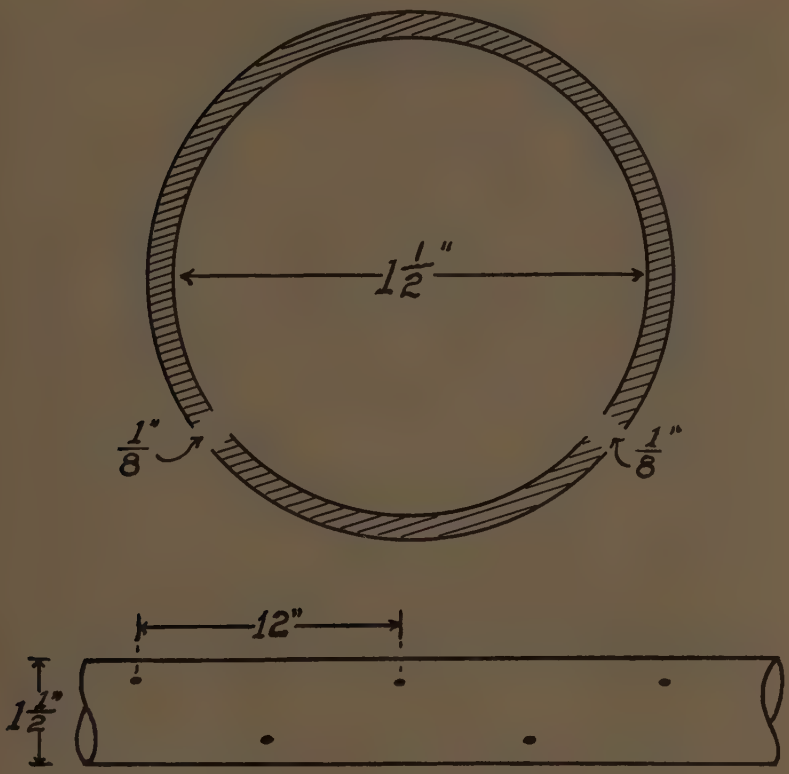

FIGURE 11. DETAILS OF THE BURIED PIPE

Upper: End view, showing size and lateral position of holes for the escape of steam. Lower: Bottom side of pipe, much reduced, showing distance between holes

lay the pipes from 6 to 12 inches deep. The deeper they are laid, the farther they may be apart; for example, 7 or 8 inches deep by 12 inches apart, 10 to 15 inches deep by 15 to 20 inches apart. The laying is done by a crew of three to fifteen men, who plow a furrow or dig a trench, lay the first pipe, and cover it while digging the next trench, and thus proceed across the house. A 17-foot house without posts then requires two sets of either seven or eight pipe lines spaced 12 to 15 inches apart (figures 12 and 13). One end of each pipe protrudes from the ground a foot or two by means of a 2-foot extension on an elbow, and is provided with a union by which it is attached to a cross header, made of 2½- to 3-inch wrought-iron pipe. The far end of each buried line

FIGURE 12. A BURIED-PIPE INSTALLATION READY TO OPERATE

The 1½-inch pipes are 42 feet long and 1½ inches apart and are buried but 8 or 9 inches. The leads and the headers are of 2½- and 2-inch pipe. A 100-horse-power boiler can handle two sets of pipe like that shown in this illustration, each covering 315 square feet of light sandy loam. Note the proximity of lettuce. Only the first row of lettuce was injured by a one-hour steaming period.

should be capped. After all the pipes are in place, the cross header is attached. Where pipes more than 80 feet long are buried, they should taper from 2 inches at one end to 1¼ inches at the other. It is important to blow out the holes in each pipe line as it is set in place, making sure that none are clogged. One header may serve from five to ten buried pipes. It is generally on the end, though it may be in the middle, of the set. If either the header or the pipe leading to it is too small, the efficiency of the buried pipes is reduced. What was said about size of conductors under the tile method applies here also.

As the steam is being admitted, the surface of the soil under treatment is covered as in the tile method. If two or three sets of pipe are employed, the crew may be kept fairly busy digging up and resetting one while the other is in use. It requires from ten to twenty minutes for four to

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FIGURE 13. INSTALLATION OF PERFORATED PIPES

Upper: A crew of six men digging perforated pipes into position. The 16 pipes can be dug up in twenty minutes and reset 15 inches deep in fifty minutes more. After a two-hour steaming period a temperature of 150° F. is obtained 19 inches deep. Lower: Note the pipe-scissors type of connection from the leads to the headers

six men to lift a set of eight pipes 40 feet long, and from forty to sixty minutes to reset them in a new position. A horse and chain may be employed to drag the pipes, one by one, to their new trenches. In this way there is less trampling of the freshly sterilized soil, and a crew of four men can make a change in less than an hour if pipes are buried

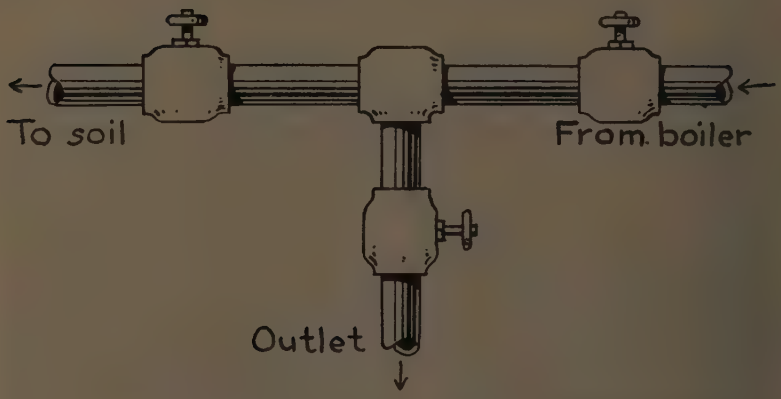

FIGURE 14. A BLOWOUT ASSEMBLAGE TO RID THE LINES OF CONDENSED WATER BEFORE TURNING STEAM INTO THE SOIL

only 9 inches below the surface. It is wise to have some sort of blow-out assemblage on the lead running to the header so that condensed water can be blown out of the lead just before turning the steam into the buried lines (figure 14).

The cost of two units suitable for a 100-horse-power boiler and consisting of seven 1½-inch pipes 40 feet long, fed by a 2-inch header 8 feet long and steaming an area of 330 square feet each in one hour, is approximately from $150 to $200. This is comparable in cost with an inverted-pan outfit covering a similar area, the next method to be described. The pipe method sterilizes 3 to 8 inches deeper than the pan in the same or a little longer time, but requires considerably more labor. Where more time is taken for deeper sterilization, comparable with the buried-tile method, the coal consumed is fully as much as with the tile method. Where shallower sterilization, comparable with that done with the pan, is accomplished, the coal consumed is about the same as in the pan system.

The inverted-pan method

The inverted-pan method does not sterilize to as great a depth as either the buried-tile or the perforated-pipe method. It nevertheless offers a very satisfactory way of sterilizing under certain circumstances. For example, seedbeds and benches can be treated satisfactorily with a pan (figure 16). The same holds true for ground beds, except where it is desired to grow cucumbers and tomatoes in nematode- or wilt-infested soil. These last two troubles are not so completely eradicated by the pan as by the tile method, especially in fairly heavy soils where the heat does not penetrate so easily as it does in the light porous soils.

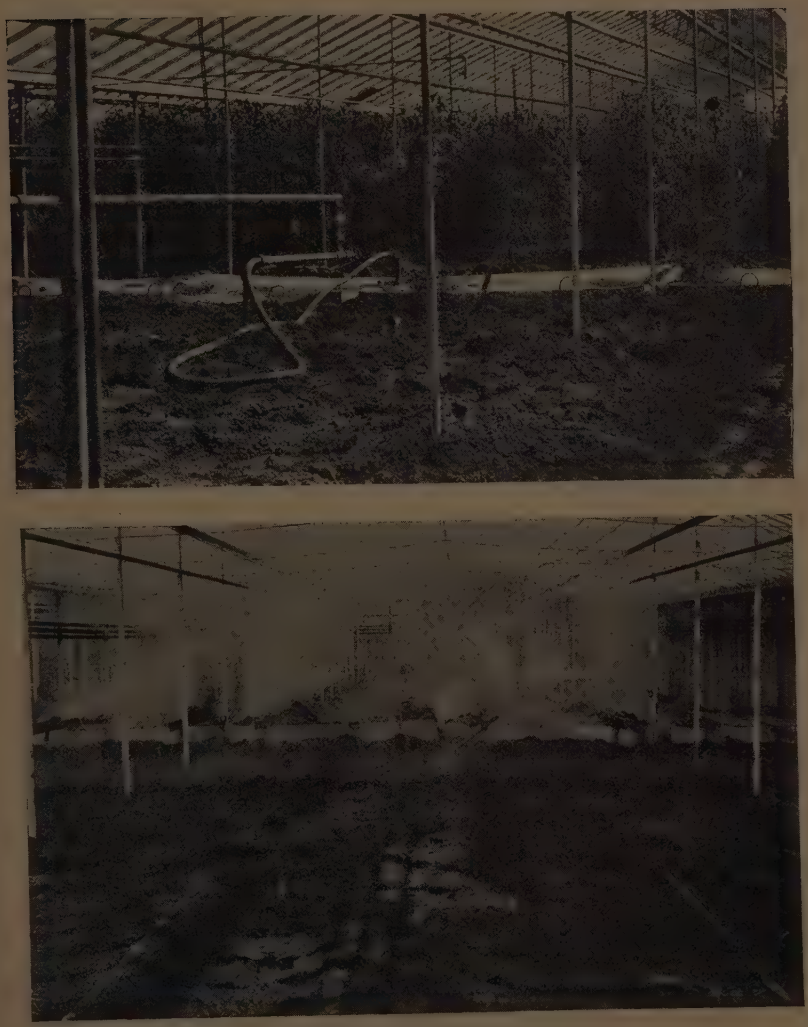

FIGURE 15. INVERTED PANS IN USE

Upper: A battery of 4 pans, each 10 by 7 feet, spanning a 30-foot house and fed by one 3-inch lead with flexible steam hose. Refer to figure 17. Lower: A similar set of pans, but each one is fed by a separate 1½-inch lead on the ground

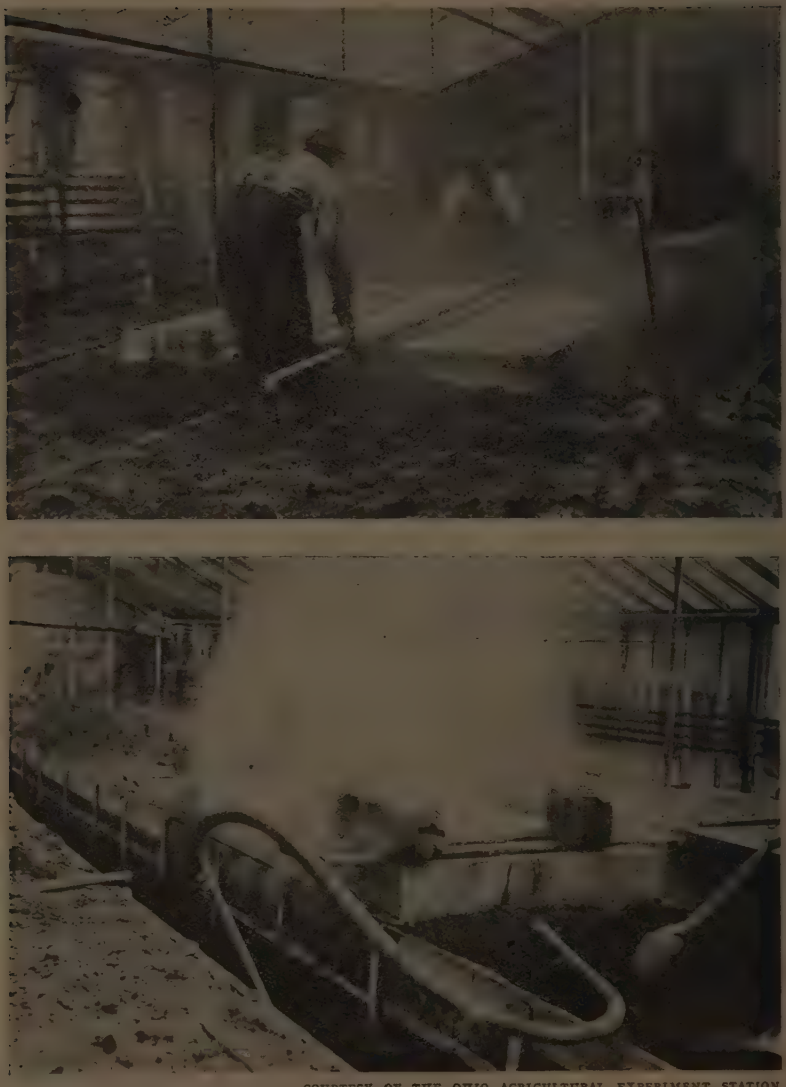

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FIGURE 16. A SINGLE INVERTED PAN IN USE

Upper: A pan covering 75 square feet is about as large as two men can handle. Lower: The pan method can also be adapted to bench soil sterilization

The apparatus consists of a rectangular galvanized-iron pan measuring about 7 by 10 feet and from 6 to 9 inches deep. The pan is inverted over the soil, and steam is admitted under pressure. The size and the shape of the pan may vary with the width of the greenhouse and the position of the purlin supports. A set of four such pans covers the entire width of a 30-foot house and steams 300 square feet at a time. The pans should be made of 20- to 24-gauge galvanized iron. Sometimes heavier material is used for the sides than for the top. With 20-gauge or lighter material the rim should be reinforced with a thin piece of strap iron, leaving the edge as sharp as possible so that it can be forced into the ground. If 14-gauge galvanized iron is used for the sides, extra reinforcing will not be needed. Suitable reinforcement of the body of the pan with 2-by-4-inch pieces of lumber, with angle irons, or with pieces of gas-pipe, must be provided to insure rigidity. Handles are fastened on the two ends of the smaller pans and at the four corners of the larger, heavier ones. A notch is left in one side to permit entrance of the steam pipe, or a 1¼-inch pipe is built into the pan with suitable union on the outside for connection with a flexible steam hose.

The weight of such a pan varies from 300 to 500 pounds. Still larger pans are now used, but these are lifted by pulleys. A heavy pan is preferable to a light one, since steam can be used under higher pressure to obtain deeper penetration without lifting the pan off the ground. Weights, such as concrete blocks, sacks of sand, or pieces of steel rail, may be placed on the corners of the pan (figure 16) and soil banked around the sides to help to force the steam into the ground.

In figure 17 are shown the details of three satisfactory assemblages for a battery of four pans, suitable for use in a 1- to 4-acre greenhouse. For smaller houses and out-of-door seedbeds one or two pans are generally sufficient (figures 16 and 21). The No. 1 assemblage requires a minimum of time to set up, is convenient to operate, and delivers the hottest possible steam to the pans. The 2½-inch lead may be suspended in the air or, as in the other assemblages, it may rest on the ground. In No. 2 the leads are on the ground and the plugs are arranged in them at 10-foot intervals, one being removed at each new pan position to permit the attachment of a tee, with a short delivery pipe entering a pan on each side. Leads of 1¼ inches serve well in a small house 100 feet long, while 2-inch pipes should be used in very long houses. These leads may taper to 1¼ inches at the far end. The third type of equipment probably delivers steam efficiently to the pans in a long house. Each pan may be moved independently of the others. This is some advantage, especially if the soil is wetter on one side of the house than on the other. The cost of this assemblage can be lowered some $50 by

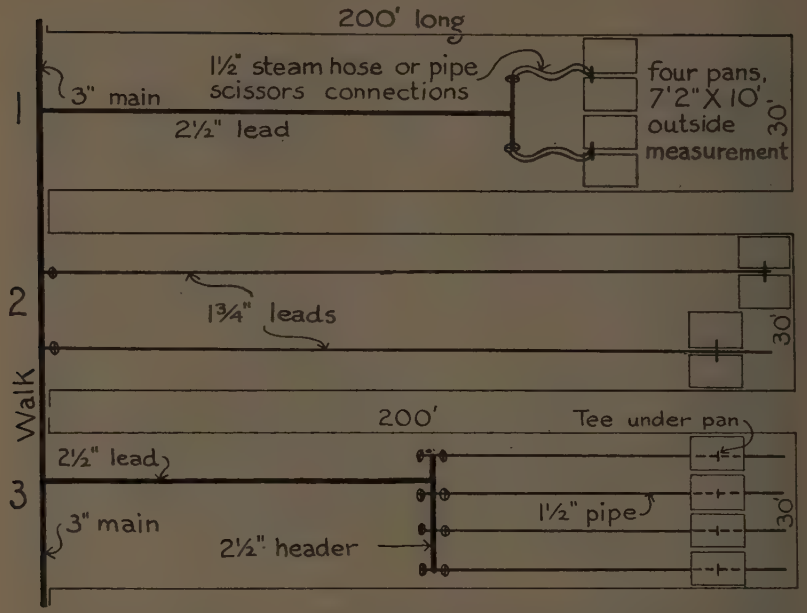

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FIGURE 17. DIAGRAM OF THREE SATISFACTORY ASSEMBLAGES FOR THE INVERTED-PAN METHOD

the use of two secondary leads instead of four. Assemblages 1 and 3 are the best arrangements for a long house. The first may be cheapened by using scissor-pipe connections in place of steam hose (figure 13). The pans will last from two to six years, while the pipes should last ten years or longer with ordinary care. Although galvanized pipe is preferred by most growers, black iron pipe gives good service and is cheaper.

The cost of materials ordinarily should not exceed from $25 to $40 apiece for the pans when made by the local tinsmith, and from $100 to $200 for the necessary pipes, valves, steam hose, and fittings.

Labor-saving devices

Brief descriptions of four successful improvements over the simple pan outfit already described are now given for the man who is at all mechanically inclined and who wishes to do the maximum amount of steaming with a minimum of labor.

The first is designated as the *Darrow hanging pan* because it is suspended from hay tracks and is lowered and raised by turning a crank

and, instead of being carried, is pushed to its new position, as shown in figures 18 and 19. It is perhaps suited only to narrow houses (15 to 20 feet). Angle-iron hay tracks may be hung under the gutters temporarily, and hay-track hangers placed on these tracks. A convenient mechanism for winding the ropes or chains attached to the pan is the ordinary wheel or crank used to raise and lower the ventilators. A pan 15 or 20 feet long by 5 to 8 feet wide and weighing approximately 1000 pounds can easily be handled by two men. The top of the pan may be of 22-gauge galvanized iron and the sides of 14-gauge. Five angle irons or 1½-inch pipes may be bolted across the pan to hold it rigid, and two or three pieces of railroad rails laid on top lengthwise will give additional weight when in use.

With a boiler of 100- to 200-horse-power capacity a battery of three or four such pans covering from 400 to 600 square feet can easily be fed from a 2½-inch lead so that a good job of steaming is done in one hour. By starting one pan fifteen or twenty minutes in advance of the next one, two men are kept fairly busy without any hardship. An acre house can thus be steamed in from ninety to one hundred and forty hours.

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FIGURE 18. DARROW HANGING PANS

These pans are 15 feet long and cover 112 square feet each. Two men can easily operate four of these pans, moving them every hour

FIGURE 19. AN ARRANGEMENT FOR MOVING THE DARROW PAN

The pan is raised and rolled along to a new position by a hay-track mechanism. When in use the pan is braced against the gutters

As with all other steaming methods, the soil must first be dry, plowed, and thoroughly pulverized to insure good penetration.

A second labor-saving device which is gaining in popularity in narrow houses (12 to 17 feet) may be called the *Miller one-man underslung pan.*

This is specially suitable where the ground beds are bordered by concrete walks (figure 20). It consists of a heavy pan 8 by 12 feet in size suspended on a steel frame, all of which is mounted on four small wheels running on the edge of the concrete walk bordering the beds.

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FIGURE 20. THE MILLER UNDERSLUNG PAN

Upper: An original wooden-framed Miller pan in use. Lower: An improved steel-framed Miller pan in use in a house that is 12 feet 9 inches wide. One man can raise the pan about a foot by operating the crank on the right; the pan is then rolled a few feet to a new position

This pan is elevated and lowered by a crank. The operator winds or unwinds, with one crank, four ropes on a drum in the center of the supporting frame. The crank is on the side so that the operator remains on the concrete walk, never stepping on the sterilized soil. The simplicity of operation enables one man to look after two pans. At night the fireman may take care of one. The pans are left in position for thirty to sixty minutes at a time.

A third device, the *Thompson rolling pan,* which is named after its originator, overcomes the necessity of stepping on the freshly sterilized soil when lifting the pan by rolling it over into its new position. It is really three pans in one and looks like a big, hollow, 3-sided prism (figure 21). A small block and tackle enables one man to handle the outfit. A 3-way 1¼-inch pipe inside the prism with a valve on each arm and a single union at the center for the attachment of a flexible steam hose enables the operator to turn the steam off and on as desired. It is made of similar materials as the previously described pans. The size of such a pan will depend upon the width of the ground beds and the doors through which it must be taken.

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FIGURE 21. THE THOMPSON ROLLING PAN

The use of this kind of pan reduces the probability of immediate recontamination of the soil by enabling the operator to stay on untreated soil and to pull the pan toward him every hour with a block and tackle

For out-of-door seedbeds a portable boiler of 20 to 50 horse power should be employed. This will care for a pan area of 60 to 150 square feet, giving good temperatures in an hour to a depth of from 5 to 10 inches. A convenient device for lifting and moving a larger pan than could otherwise be handled by one man is shown in figure 22. It con-

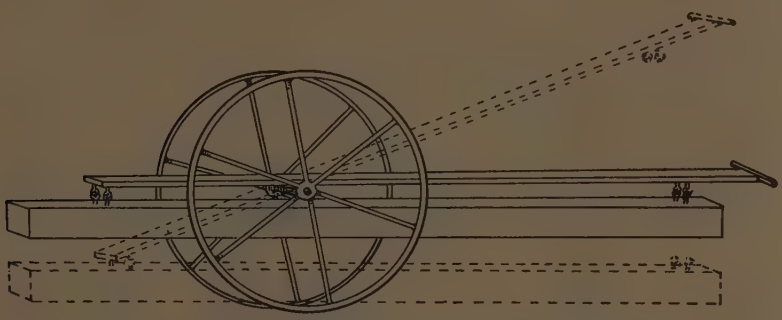

FIGURE 22. A SIMPLE CONTRIVANCE FOR LIFTING AND MOVING A HEAVY STEAM PAN
The dotted lines show the position of the pan when use

sists of a pair of wagon wheels on an axle a little longer than the width of the pan. A stout wooden frame over the axle, nearly as long as the pan, acts as a lever, with the axle as a fulcrum. The pan is hooked to the short end of the lever, and by pulling down on the longer end the entire pan is lifted from the ground several inches and may then be wheeled into a new position.

The steam harrow or rake

Where the only pests to be fought are weed seeds, lettuce drop (*Sclerotinia*), and damping-off fungi, the harrow method may prove satisfactory in the lighter soils. The low cost and the ease of operation may recommend this method to many; but in heavier soils, or where nematodes and Fusarium wilt are present, results indicate that it is not nearly so reliable as the other steaming methods.

The harrow itself consists of a lattuce work of ¾- or ⅝-inch pipe through which steam passes into numerous hollow, pointed spikes of ¼- or ⅜-inch pipe. These spikes are 8 or 9 inches long, and have one or two 3/16-inch holes near the tip end to let out the steam. When in use the spikes are pushed into the ground as far as they will go, and the steam is forced out through their small holes into the soil. While the length of the teeth should not be less than 7 inches, there is some latitude permissible in their number and in the size of the entire harrow. From the writers' experience it seems safe to say that the spikes should

not be farther apart than 6 inches each way. Harrows have been made with spikes 8 inches apart but they are less efficient and so are not to be recommended. A safer distance for the spikes is 4 inches each way. A convenient size for the harrow is 3 by 9 feet or 3 by 12 feet, although smaller ones 3 by 3 feet have been used. The shape of the beds on which it is to be used will largely determine its dimensions. Some idea of the details of its construction may be gained by referring to figure 23.

As with all other steaming methods, a thorough preparation of the soil beforehand is essential for success. This is particularly true if the soil is rather heavy or contains a little too much moisture. In fact, the harrow method should really not be employed on heavy soils. On light sandy soils it is possible to have the soil too dry, better results being obtained when the upper inch or so of soil is moist. Weights may be used as with the pan to hold the harrow down while in use. It is an excellent plan to cover it with a light metal pan to help confine the steam while operating. The soil should be covered for some hours after steaming to help hold in the heat as in other methods. Special attention must be paid to see that the spikes do not become clogged. This is perhaps best guarded against by not turning the steam entirely off when about to lift the harrow and by turning the steam on full for a moment just before pushing it down into a new position. Even with these precautions it will be necessary to do more or less hand picking to keep all spikes in working order. This is where operators fail most frequently and is the reason why the harrow has so often proved inadequate in doing a thorough job. It is, therefore, no longer recommended preceding the growth of high-temperature crops (tomatoes and cucumbers) where nematodes or wilt fungi are to be eradicated.

The cost of steaming by the harrow method is lower than with any other, even though construction costs are as high as for a set of pans. This is largely because it is a shallower, more superficial method. From the clouds of steam arising in a few minutes (ten to fifteen) from the harrow, operators have assumed it unnecessary to steam as long by this method as by the others. Furthermore, tests have indicated that steaming for an hour gives very little better penetration than steaming only thirty minutes, because in thirty minutes the steam will have found a passage directly up through the soil from the tip of the spike, which becomes a path of least resistance for all steam thereafter. Where rakes are moved every thirty minutes instead of every hour, the coal consumed is seldom more than 25 or 30 tons an acre, or 1.2 pounds for each square foot. The labor charge is similarly reduced so that the entire cost rarely needs to exceed ½ cent a square foot. But the depth of good sterilization is proportionately reduced, being from 3 to 5

FIGURE 23. A SMALL STEAM HARROW IN OPERATION ON A LIGHT SANDY LOAM

This apparatus has not always proved efficient in holding down nematodes and Fusarium wilt, especially on the heavier soils. It does better with a metal cover on the top and sides

inches, or about half as deep as commonly obtained with the pan method and one-fourth as deep as that with the tile method. Where a pan is inverted over the harrow, undoubtedly much better results may be expected of this equipment. In that case the teeth may not need to be so close together.

Steaming small quantities of soil for flats

In large greenhouses it is frequently desired to steam a small quantity of soil in which to start seedlings. A number of ways suggest themselves where a steam supply is available. A pan can be inverted over a portion of a bench or ground bed (figure 16), or tile or perforated pipe can be laid in a section of a bench (figure 7), but it is often more convenient to sterilize flats and soil in one operation. For this one can employ a large pressure cooker (figure 24), obtainable from dealers in new or used canners' supplies at a cost of $100 to $400, or one can make a chamber of brick or concrete large enough to hold from 10 to 100 flats of soil at a time, piled one above the other. With a tight door, a 1-inch inlet for the steam and a ½-inch outlet for the condensate at the bottom, these flats of soil can be steamed in a few hours (figure 25). A great saving in plants, a more vigorous growth of seedlings, and earlier transplanting dates can thus be enjoyed in such sterilized soil at a relatively small expense.

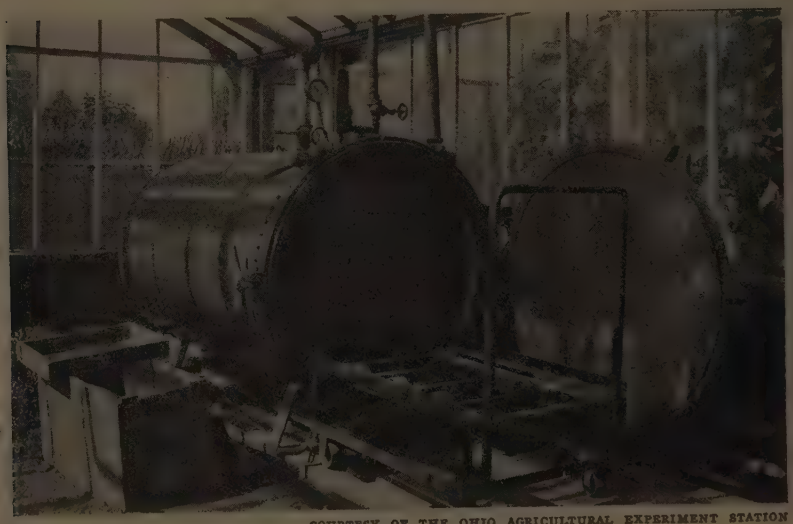

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FIGURE 24. A CANNER'S PRESSURE COOKER CONVERTED INTO A SOIL STERILIZER
Pots and flats can be steamed in a short time in this cooker

FIGURE 25. A CONCRETE STEAMING CLOSET

Pots and flats of soil may be heated by passing live steam through the closet for a few minutes. A tight-fitting door is an important consideration

English steam bins

Many growers, truckers, and greenhouse men who do not have steam-heating plants on their property but do have certain pests in their soil which really demand high-temperature sterilization for effective control, are in a position to profitably employ one of the English methods of soil sterilization by heat.

One of these methods requires a small boiler (15 to 50 horse power) and a wooden bin or low box in which the soil may be sterilized by the truckload. If two such bins are employed, one can be in operation while the other is being emptied and refilled. These steaming bins may be built either in a head house or out of doors. In place of matched boards the walls can be built of brick or concrete for greater permanence. They can be made community affairs or cooperative projects at very little cost to any individual. Their use simply involves the labor of firing the boiler and carting the soil to and from the greenhouse, the seedbed, or the cold frame. The details of such an outfit are given in the following paragraph.

Suppose a 25-horse-power boiler is available that is capable of maintaining a steam pressure of 50 to 70 pounds. This should sterilize the contents of a bin holding about 3 cubic yards of soil in less than two hours. As the soil should usually not be more than 15 inches deep, this would limit the dimensions of the bin to 6 by 10 feet by 18 to 24 inches high. In England smaller bins than this are employed. A larger one would simply require a longer steaming period or a larger boiler. A removable, perforated false bottom is supplied to hold the soil, under which a 1-inch pipe, with a short T on the end of it, is laid to admit the steam. Suitable perforations in the false bottom, ¼-inch holes bored at 4- to 6-inch intervals, admit the steam up through the soil. A suitable lid or covering of boards or heavy canvas or building paper must be provided. It is highly desirable to have at least one side of the bin removable or on hinges at the bottom to facilitate emptying the bin and removing the false bottom. If the bin is elevated above the ground, its contents can be more easily shoveled into waiting trucks, and if a platform is built on the opposite side, fresh soil can more easily be dumped into the bin from the truck thus elevated above it.

In place of the perforated false bottom one can supply a perforated grid of ¾-inch steam pipe, like a great fork with the three or four tines, lying parallel on the bottom about 15 inches apart and extending the length of the bin. At 6-inch intervals along the sides of these pipes ⅛-inch holes are bored for the steam to escape. The far ends are capped while the opposite ends are connected to the steam supply by a union in the corner of the bin. The grid is thus easily removed

to clean the bin each time it is used. The holes in the grid must be kept clear by blowing steam through them and by hand picking.

This method is essentially like the buried-pipe method and is equally efficient, provided the steam is left on until several tests with a thermometer show that all parts of the soil mass have attained a temperature of 200°F. If the soil is left in the bin overnight or until it has cooled down considerably, there is danger of recontaminating it by carrying it back to the bed in the same wagon or truck which brought it. To avoid this, the wagon or truck may be rinsed out with a good disinfectant, such as a 2-per-cent formaldehyde, acetic acid, or copper-sulfate solution. If the soil is steaming hot when shoveled into the truck, there is less danger from such recontamination.

Various modifications of the foregoing description will suggest themselves to most growers, such as lining a wooden box with sheet metal to make it tighter, building it half in the ground or with a concrete or brick floor to conserve steam, providing an outlet in the latter cases for draining off excess water and mud.

DRY HEAT

Surface burning

Surface burning, one of the oldest methods of soil sterilization, consists in burning wood, brush, or dry grass over the area to be treated. When the fire is intense enough for a given time, the heat will penetrate a considerable depth into the soil, and will kill parasitic organisms as surely as does steam. In pioneer days it was about the only source of heat, and as wood was cheap growers could afford to use it. In newly cleared land, places where brush piles were burned dotted the fields. The early settlers learned that delicate plants like watermelons, muskmelons, and even beans, could be grown in these spots when they would damp-off otherwise.

At the present time surface burning is far too expensive. It has the added disadvantage of destroying the humus in the soil. This results in sudden drying, because humus largely determines the moisture-holding capacity of a soil.

A modification of surface burning that is practiced now in the Catskill cauliflower district of New York, in England, and other places, is the heating of soil in a pan. The pan, made of fairly heavy galvanized sheet iron, is set over an open fire, or placed on a concrete or brick oven. The length and the width of the pan are made to fit the area of the fire box, and the depth should never be greater than a foot. The soil, which first has been made wet enough so that the humus will not burn, is placed in the pan. The time of heat application is variable,

for it is difficult to gauge the intensity of the heat under the pan. But when the temperature of the soil reaches 180° to 200° F. for at least ten minutes, the sterilizing process is sufficient. It may be necessary to stir the soil occasionally to keep the bottom from burning, and the top from remaining too cold. Boards or burlap may be employed for covering the surface and helping to retain the heat and the moisture. A pair of accurate thermometers are advised for determining the temperature; if these are not available, small potatoes can be placed in the soil, and when these are cooked, the soil will have been sterilized sufficiently.

The pan-roasting method is justified when only small amounts of soil are to be treated, but it is impracticable for large beds, since it is a very time-consuming operation and therefore too expensive.

English ovens

Where a supply of steam is out of the question it is possible to bake soil over a long brick flue built just below the ground level. This Warburton apparatus has been described as follows (figure 26): A trench is first dug, 20 feet long by 4 feet wide and 3 feet deep, the bottom being given a gentle upward slope of about 1 inch in 2½ feet from the fire-box end to the chimney end. Bricks are first laid on the sloping bottom, and a 9-inch brick lining is constructed on the sides of the trench. The trench is then divided into three flues, each 6¾ inches wide, by the construction of two division walls 11 inches high. Frequent holes in these walls permit intercommunication of the hot gases between all three flues. Fire tiles 23 by 11½ inches are used to cover the flues, resting partly on the inner edge of the outer walls and partly on the flue division walls. These tiles form the bottom of the trench or trough which holds the soil to be heated. Ordinary bricks are too thick for the floor of this trough. The fire box is about 2 feet long and is sunk so that its fire-brick roof is just level with the top of the flues. It is also lined with fire bricks, and its floor consists of 14 fire bars 22 inches long, spaced 1½ inches apart, and gradually sloping towards the flues. These fire bars are supported on 3 crossbars held up by the brickwork. Fire clay is spread over the arched bricks, forming the roof of the fire box, so as to form a continuous bottom to the soil trough out over the fire box. A chimney is built of brick at the opposite end and provided with a damper for controlling the draft on windy days.

Soil is brought in wagonloads or by wheelbarrow and dumped into the soil trough above the flues to a depth of about 9 inches. A coal fire is kept in the fire box, and the soil is covered with canvas or boards. If the soil is not too dry, there is moisture enough in it to keep it from "burning" out. When the temperature has been raised to 200°F. in all

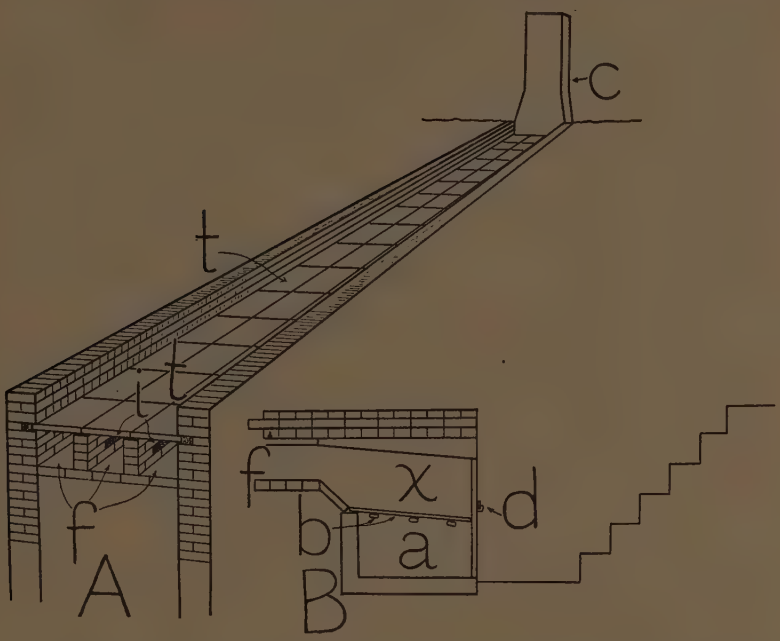

FIGURE 26. DIAGRAM OF THE WARBURTON SOIL STERILIZER USED IN ENGLAND

A: The brick-lined soil trough from the fire pot end, showing the flues (*f*) intercommunicating at *t*, the fire tiles (*t*) covering the flues, and the chimney (*c*) at the far end. B: Side elevation of the fire box (*x*), to be attached to A, showing the ash pit (*a*), the three crossbars supporting the fire bars (*b*), and the door (*d*)

parts, the soil is shoveled over onto a pile and hauled back to the beds whence it came, or left in a pile for three or four weeks before seed is sown in it again.

HOT WATER

Small 4-inch pots of soil may be sterilized by a 5-minute immersion in boiling water, and trays from 1 to 2 inches deep by a slightly longer period of treating. It has also been suggested that applying 7 gallons of boiling water for each square foot of shallow bench soil will give successful results. When hot water was used on ground beds, however, the senior author failed to procure uniform results in the control of nematodes. The soil became puddled quickly and the excess water was slow in finding its way downward. Killing temperatures of 140° to 160° F. were obtained at irregular, shallow depths. Nematodes were evidently not killed much below the upper 3 inches of the bed even where the soil was sandy.

The only place where hot water may be of use is in the home where only a few flowerpots of soil need sterilizing. A wash boiler partly full of boiling water and supplied with a false wooden bottom can be set on the kitchen range. The pots are then immersed to such a depth that their tops are just even with the surface of the water. If the fire is kept going briskly, two or possibly three pots can be treated at a time, and successive pots as fast as the time requirement for treatment will permit. Each size above 4 inches will require about two additional minutes of treatment above the original five minutes required for 4-inch pots.

SOIL TREATMENT BY FLOODING OR BY DRYING

Although land that is flooded for a part of each year is said to be free from nematodes, flooding has not proved satisfactory in a number of trials as a practical control of this pest. Even though flooding were successful, it would have slight economic value. It would be almost impossible to flood the floor surface of an entire greenhouse or hotbed and keep the water there for any length of time. Furthermore, it has not proved beneficial in killing pathogenic fungi and bacteria, so this practice is not recommended.

A quicker method of killing nematodes consists in air-drying the soil until no more moisture is given off. From one to two weeks of this dryness will kill the nematodes. One of the difficulties in this process is the impossibility of drying large enough quantities of soil to fill the ordinary greenhouse bed. In addition, desiccation of this kind has no ill effect on parasitic fungi and bacteria, therefore, it can be used only to kill nematodes in comparatively small quantities of soil. If in the private home, a few flowers, or a few flats of vegetable seedlings are grown, and nematode-infested soil must be used, drying the soil near the furnace or stove for a few days to two weeks is practicable. Stirring the soil occasionally will greatly facilitate the desiccation process.

TREATMENT WITH CHEMICALS

FORMALDEHYDE

In many greenhouses the necessary apparatus is not available for steam sterilization. If nematodes are not to be combated, a chemical may be applied to the soil to control soil-borne pathogenes. Among the most common of these chemicals is formaldehyde. This is sold in the form of a colorless liquid with an approximate strength of 40 per cent. It is an excellent fungicide, mixes readily with water when diluted, and is reasonably cheap as compared with other chemical disinfectants. In

addition, no unfavorable residue is left in the soil to alter its degree of alkalinity, its physical condition, or to injure the seed when planted a reasonable time after the treatment. Its fumes permeate all parts of the upper layers of soil and then gradually drift away, especially if a covering is placed over the bed for a few days and the surface afterwards is exposed to the air.

The use of formaldehyde has two or three disadvantages; namely, it does not kill nematodes nor the Botrytis fungus readily and is not effective against most weed seeds. Furthermore, it requires heavy wetting of the soil, which is not always beneficial, and often it takes too long to rid the soil of the fumes and get it into good condition to sow or plant. The fumes are so strong that when breathed they cause pain in the mucous linings of the nose and the throat. If the hands are dipped into the diluted liquid for too long a time, the skin becomes dry and harsh. It causes death when taken internally in relatively large doses. The chemical, however, is perfectly safe to apply and will cause no serious effects in ordinary handling.

The time for sterilizing with formaldehyde in many cases is determined by the fact that nearly two weeks are required after the application before seeds may be sown. Since the hotbeds and cold frames usually are seeded down as soon as the frost is out of the ground, it is imperative that the formaldehyde be applied in the fall before the ground freezes. The fall treatment is otherwise desirable in that the weather is inclined to be pleasant then, and the rush of other work generally is not so great. But when the beds are treated in autumn, every washing rain of the winter months may be a source of recontamination. It is for this reason that not only the beds should be wet down with the solution but also the boards that form the sides and the adjoining paths or all the areas between the beds if they are reasonably close together. If there is a chance of washing in from the outside, the beds should be protected with small ditches and dams in such a way that the water and washing dirt will be led away.

Much of the success of sterilizing depends upon the condition of the soil when the solution is applied. If the formaldehyde is poured on hard, dry ground, it will not penetrate enough to be of any value. On the other hand, if it is mixed with saturated, loose soil, the fungicide either is diluted to such an extent that it is of little benefit or the surplus liquid flows away and is lost. The soil should be spaded or plowed, the clods well pulverized, and barnyard manure or other organic matter applied, before the sterilizing is begun. The soil should be damp but not too wet. Certain sclerotia, or resting bodies, of fungi are much more difficult to kill when they are dry and in a perfectly dormant

stage than when they have been wet for some time. If the beds are outdoors, it is well to do the treating at least a few days before heavy rains. During such a precipitation the amount of water cannot be governed, and too great a dilution of the formaldehyde may result.

The dilutions of formaldehyde suggested in the various publications are so variable that it is difficult for the grower to determine what strength to use. The range extends all the way from 1 part in 42 parts of water to 1 part in 400 parts of water. But the majority of the research workers now seem to agree on the formula 1–100, and 1 gallon applied to each square foot of soil, or 1–50, and ½ gallon applied. The recent publications seem more generally to favor the latter dilution since it requires only half the amount of the 1–100 dilution and still penetrates far enough to be successful.

Still another suggestion is that a determination be made of the amount of water needed to saturate each square foot of soil and the 1 gallon of the concentrated formaldehyde mixed with enough water to saturate 100 square feet. This procedure prevents overdrenching.

In Pennsylvania Beach experimented with concentrated solutions such as 1–16, 1–25, and 1–33. When he used 1 gallon of the commercial formaldehyde in 24 gallons of water, and applied 1 quart for each square foot, then watered the soil heavily with a hose, he obtained results that were nearly enough comparable with the 1–50 and 1–100 dilutions to justify the use of the more concentrated formula if apparatus were not available for treating with large quantities of the more dilute formaldehyde.

For general use 1 gallon of commercial formaldehyde in 49 gallons of water and ½ gallon of the diluted solution for each square foot is advised. If the soil does not take up all the water at once, the treatment can be divided into two or more applications at thirty-minute intervals. Soil for shallow beds, flats, or pots may be placed in a tight box or a closed room, and, as it is being put in, the 1–50 formaldehyde solution may be sprayed over the successive layers until they are thoroughly wet. The treatment may be made at any time and the soil left there until time for potting or filling the flats.

There are many devices for applying a liquid to the soil. An elevated wooden or metal tank may be provided for each group of hotbeds or greenhouses. The tank should be connected with the beds by iron pipes or rubber hose, so that the material may be fed to the soil by gravity. Such an arrangement saves a very large amount of labor and reduces the cost of the treatment. Small beds may be wet down with pails or watering pots. Pots, pans, and flats can be dipped into the solution, then stacked up to dry.

The fumes of formaldehyde are given off so readily that if no effort is made to hold them in the soil, they may not penetrate deeply enough to prove effective. In order to overcome this difficulty, it is advised that after the solution is poured into the soil, a covering of paper, mats, old carpet, canvas, or boards be provided for a day or two to hold the fumes. This covering is removed later so that the fumes may escape and the excess water evaporate. It has been found that fairly successful sterilization can be obtained even when the coverings are omitted. This omission, however, is recommended only where the area to be treated cannot be covered economically either because of its size or the expense of materials, and then only in heavy soils, which hold the gas more firmly than do those of a loose, sandy texture.

As soon as the soil is dry enough to rake, it should be stirred to hasten the drying process. Even with this precaution it will be from eight to fourteen days, or even longer in very heavy soil, after the application has been made before the soil will be dry enough and the formaldehyde fumes dissipated sufficiently to permit the planting of seed.

It has been suggested that seed may be planted before all of the formaldehyde has escaped from the soil, so that the seeds are also subjected to some of the sterilizing influences. But as it is impossible to know the exact strength of the fungicide at any given time during the period of aeration, it is a great risk to place valuable seeds into such intimate contact with formaldehyde which can destroy seed germination very quickly even when in dilute form.

The cost of formaldehyde sterilization is about the same as that for steam, or slightly higher. Since the prices of the chemical may vary and as a large proportion of the total cost is the sum spent for the chemical, the exact expenses cannot be given. Another reason for variation in cost is the handiness of the water, the materials, and the apparatus for applying it. A sash covers 18 square feet. Two men can drench the space covered by 250 sashes in one day if everything is readily available. This space requires 45 gallons of the concentrated formaldehyde and 2250 gallons of water. If the chemical can be bought at 14 cents a pound, or $1.13 a gallon, and workmen receive $6 a day, the cost for formaldehyde sterilization would be almost 25 cents a sash, or approximately $14 for a thousand square feet ($600 an acre). Where it is necessary to cart water for even a very short distance, the cost is much increased.

In order to hold the damping-off fungi in check, some growers place a teaspoonful or slightly more of formaldehyde in each gallon of water when they water their young plants. There is such a narrow margin

of safety between the amount of the fungicide sufficient to kill the pathogenes and that which will injure the seedlings that the practice is not generally recommended.

ACETIC ACID

Acetic acid, the active agent in vinegar, has long been known as a food preservative, but has only recently been tried as a soil disinfectant. It has several advantages over formaldehyde, among which are the fact that the fumes are not so unpleasant to breathe, that it is cheaper, and that in large well-ventilated greenhouses it can be used safely near beds where plants are growing. If the greenhouses are low or poorly ventilated, however, the fumes in the air become concentrated enough to injure living plant foliage. It kills weed seeds fairly well, and although it alone does not reduce the percentage of nematode infection, it does seem to check the growth of these parasites so that the galls do not grow so large, and in consequence the crops on the treated soil look better than on the untreated. It cannot be used in beds where plants are growing. Its fumes stay in the soil from eight to fourteen days, depending upon the amount applied and the type of soil, so that seed should not be planted during this period of aeration. Another precaution is that the grower should not be deceived about the strength of acetic acid by thinking it is nondeleterious because it is the same as that in vinegar. Applications of the concentrated acid will take the skin off the hand within a few days, even though it does not seem to cause injury at the time the hand is put into the liquid. Relatively small doses taken internally will cause death. Notwithstanding these handicaps, it is very simple to handle the material without any injury to the body. When it is once diluted for soil disinfecting, it is no longer dangerous in any way.

Acetic acid has not been tested as thoroughly and under as varied conditions as has formaldehyde, but its use has been found effective often enough so that it can be recommended at least for the control of such soil-borne fungi as cause damping-off of vegetable seedlings, lettuce drop, radish root-rot, ginseng root-rot, tobacco black root-rot, tobacco brown root-rot and probably others. It can be purchased in dilutions varying from 28 per cent to glacial acetic which is almost 100-per-cent pure. The prices for the different percentages are fairly relative, although the usual quotations favor slightly the higher concentrations.

The material is diluted by mixing 1 gallon of the glacial acetic acid in 99 gallons of water. If more dilute concentrations are bought, the dilutions vary in proportion. If, for instance, the grower buys 56-per-

cent acid, he mixes almost 2 gallons in 98 gallons of water. One-half gallon of the diluted liquid is poured over each square foot of soil.

The method of making the application and the precautions necessary are the same as stated for formaldehyde. The treatment will make the soil more acid only for a short time, and during this period certain soil fungi that would not grow otherwise make a growth over the entire soil surface where they have the gray appearance of a rather heavy application of commercial fertilizer. They are not harmful to growing plants and will disappear as soon as the soil returns to its normal degree of alkalinity.

The cost for labor and apparatus in applying acetic acid should be the same as that for formaldehyde, but the cost of the materials is only about half, since only half as much of the acid is used as of the formaldehyde. A gallon of glacial acetic acid weighs approximately 8.76 pounds, and the cost for this material usually is quoted at about 13 cents a pound, or $1.14 a gallon. This quantity is sufficient for 200 square feet of soil. With the cost of labor included, the total cost of applying acetic acid would amount to $8.50 for a thousand square feet of soil. or $375 an acre.

A recent note published by Jones of the Massachusetts State Agricultural Experiment Station states that if the amount of calcium cyanide recommended by manufacturers for soil disinfestation be dissolved in the dilute form of acetic acid and two applications are made with this mixture of chemicals, nematodes can be controlled. This has not yet been tried under New York State conditions, but if it proves effective in the varied soils, the recommendation will be of great value to growers who cannot procure the necessary amount of steam for heat sterilization.

LIME

Lime is not a disinfectant. But it long has been known that the growth of bacteria and fungi are influenced vitally by the degree of soil alkalinity. Some of the organisms thrive best when the soil is acid, while others can multiply only when in the presence of an alkaline solution. When potato scab is present, it is a sign that the soil contains too much lime or other material with a similar reaction. On the other hand, club-root of cabbage and related crops can occur only in an acid soil.

It has long been known that when lime is added to an infested cabbage field, the club-root disappears for a year, but eventually returns again when cabbage is planted in the same field. The trouble in the past has been that there were no definite tests for determining the acidity of soil. But this has been remedied, and a soil specialist can

now determine very accurately how much lime is required for most soils to cause the alkalinity to rise slightly above the neutral point, which is required in the control of club-root.

Until recently it was thought that any form of lime was equally effective in controlling this cabbage disease. It has now been proved that if hydrated lime or burnt lime is added six weeks to two months before the plants are set into the field, the alkalinity needs to reach only the point 7.2 pH, when 7 represents neutrality. But, strangely, when air-slaked lime or ground limestone is applied, the soil must attain the point 8 pH before the disease is held in check. This is too alkaline for good growth of cabbage and many other crops, so that only burnt lime or hydrated lime is recommended for this crop if club-root is present.

Hardly any two soils will require the same amount of lime to make them netural. Therefore, the only safe way is to have the county agricultural agent make soil tests to determine in each case how much lime is needed to control the club-root organism.

The time of application should always be in the spring unless the crop is to be planted very early, when a fall application may be necessary. In this case more lime is required, for the hydrated lime applied in autumn will change to air-slaked lime before the crop is planted.

A very satisfactory method of application is to sow the lime broadcast as soon as the plowing is done and then to disk or harrow it into the soil. Apparently when it is plowed under, the distribution is not so uniform and club-root is not controlled so thoroughly.

The exact proportion of calcium in the hydrated lime is not an important factor in club-root control. If lime high in magnesium is cheaper in price, it can be used as successfully as that high in calcium.

The seedbed should never be treated with lime for the control of club-root. It may stop infection in the bed; but when the plants are set into the field, the spores of the parasite cling with particles of soil to the root and then cause infection if the field is not limed heavily. Therefore, the best practice is to treat the bed with corrosive sublimate (page 56), to lime heavily infested areas in the field, and to practice long rotations.

CARBON BISULFIDE

In Europe, carbon bisulfide is mentioned more often as a soil disinfectant and disinfestant than any other material, including steam. Strangely, in this connection, it is given very little consideration in American literature. It is recommended by German authors especially for the control of nematodes, and a few make the statement that it will

eradicate soil fungi. Howard, in New Zealand, and Bessey, in our country, state that if holes almost a foot deep are made at *regular intervals* with a hoe handle and a given amount of the carbon bisulfide is poured in and the hole is filled with earth again, the nematodes will disappear. The dosage usually recommended is 4 ounces for each square yard of soil.

Some of the reasons given by American workers for not using carbon bisulfide are that its use is expensive, it does not kill soil-harbored fungi, that it is highly inflammable, that its odor is extremely disagreeable, and that its injurious effects on crop life persist in the soil for two to three months or even longer. It is rather difficult to figure the exact cost of application since there seem to be no reliable estimates regarding the labor required for treating an acre of soil. If one man could treat 200 square yards in a day (which seems to be a big day's work) and the cost of the material were 15 cents a pound, this treatment would cost nearly $2000 an acre.

In order to overcome some of the objectionable features of the carbon-bisulfide treatment mentioned, it has been used in an emulsion form for the control of several troublesome insects as the Japanese and Asiatic beetles. Lately the same form has been applied to the soil for the eradication of nematodes. At least two workers have reported success in their experiments, but not enough research has yet been done to justify general recommendations regarding its use. The exact amounts of the material to employ and the most satisfactory percentage of emulsion have not been determined with certainty. One gallon of a 70-per-cent emulsion or 2 gallons of a 35-per-cent emulsion diluted in 60 gallons of water, and applied at the rate of 1 gallon of the mixture to each square foot of soil, have been suggested. The only quotation of prices available is 25 cents a pound for a 50-per-cent emulsion. This would mean a cost of approximately $2000 an acre.

SULFUR AND SULFUR COMPOUNDS

A large number of acids have been tested as fungicides, but surprisingly few are toxic to pathogenes in the soil. Sulfuric acid has been found to have some use in controlling damping-off in forest-nursery beds. Its chief advantage is that its influence persists for a long while, permitting such slow-growing seedlings as pines to develop to a resistant stage before the fungicidal effect is finally dissipated. It also kills many weed seeds. The disadvantages are that the acid does not react alike in all soils, and may remain present so long that the young plants are injured severely. This can in part be overcome by watering heavily after the application.

The recipe for the use of commercial sulfuric acid requires from 3/16 to 5/8 of an ounce, depending upon the normal alkalinity of the soil, sprinkled over each square foot at the time of planting the seed. Very heavy watering is then necessary to insure the spread of the acid in the soil, and to so dilute the fungicide that it will be comparatively harmless to forest-tree seedlings.

Before treating large areas, it would be well to make a test application to determine the exact dosage of the sulfuric acid that would be safe on the crop to be grown in a given soil and the amount of water that properly should go with the dosage.

Sulfuric acid has been tried unsuccessfully as a soil disinfectant in connection with the control of Sclerotinia, the cause of lettuce drop. Apparently any of the succulent vegetable crops are as susceptible to the injury from this chemical as are the fungi which are meant to be eradicated. Therefore, it seems wise at present to limit the use of the acid to soil in which conifer seedlings are to be grown.

Nearly every chemical with any fungicidal properties at all has been tested in soil treatments of one kind or another. Naturally sulfur, and especially lime-sulfur solution, was one of the first to be tried. There seems, however, to be very little toxic effect on soil pathogenes when sulfur is added to the soil. It, nevertheless, is found to play one important part,—that of making the soil acid so that certain parasites can not grow.

Since the principal control of potato scab consists in keeping the soil acid, sulfur treatments have been recommended to decrease injury from scab. From 200 to 800 pounds of the chemical to the acre, depending upon the natural acidity of the soil, is broadcast over the plowed field and harrowed or disked in. Certain soils are deficient in bacteria that oxidize the sulfur to make it effective. Consequently, sulfur inoculated with these bacteria has been placed on the market for soil treatment.

In recent years the use of sulfur for scab control has almost ceased, except in special cases. The sulfur is toxic to most crops, and, as its influence remains for several years, any other crops in the rotation are sure to suffer. Therefore, the present recommendation is to turn under as many green cover crops as possible, to grow cultivated crops for leaching out excess lime, and to apply fertilizer with sulfate of ammonia and other acid-producing compounds. The sulfur then is recommended for small areas where the scab has been especially severe, in a field or in a garden where rotation cannot be practiced.

Beet scab is the same as that on potatoes. But sulfur cannot be used on beet soil because the crop yield is reduced in the presence of high acidity.

Eggplant is very resistant to sulfur injury, while the Verticillium that causes eggplant wilt will not grow in very acid soil. Therefore if large

quantities of sulfur are applied, the wilt is much reduced even though it is never completely controlled. The application of sulfur to the soil in growing this crop is practicable only if there is to be no rotation with other vegetables, for such large quantities of sulfur as are needed for the control of the eggplant wilt will make the soil worthless for most other crops unless large quantities of lime are added later.

COPPER COMPOUNDS

Copper is especially effective against some of the lower groups of fungi, as Phytophthora and Pythium. Its use is not recommended generally, but in cases of damping-off where Rhizoctonia is not present, where steam or formaldehyde sterilization cannot well be practiced, or where there is a chance of recontamination after such sterilization, the copper treatment has been found beneficial. Copper has the advantage of remaining in the soil for some time after the seed is planted, and thus protecting the young sprouts from pathogenes before the time of emergence. Some of the forms can be applied safely even after the plants are up. Furthermore, the material is very easy to apply and the cost is very low. For instance, copper sulfate (blue vitriol) sells for less than 10 cents a pound, and 1 pound in 25 gallons of water is sufficient to treat 100 square feet of seedbed surface. Copper carbonate is almost as cheap.

The chief disadvantage of copper is that, in some forms, as copper sulfate, it may be very injurious to plant life because it is so easily soluble in water. Even though quickly soluble it does not penetrate deeply into the soil if placed on the surface. Copper carbonate, on the other hand, may at times be too nearly insoluble to produce the maximum effect when needed. Copper, too, appears not to be very toxic against Rhizoctonia, one of the most virulent parasites causing damping-off.

Copper sulfate, or blue vitriol, is a well-known copper compound, for it is one of the active ingredients in bordeaux mixture. It usually is bought as blue crystals, but it may also be procured in a granulated form or even as a fine ground powder. One pound of the material is dissolved in 25 gallons of water, and this solution is used to wet the soil after the seed is sown. Two pints for each square foot of seedbed is recommended.

In some soils, under certain conditions, and on some crops the copper sulfate seems to work effectively, while at other times it may delay germination of the seed and retard the plant growth. Since the reasons for this difference in behavior have not been worked out completely, copper sulfate is not recommended generally. Before venturing to treat a large area, one should test a few flats or a few square feet of bed surface to see whether the chemical will injure the crop to be grown.

Copper sulfate in some cases has a use quite distinct from that of protecting plants from fungi. Certain soils, especially in some of the muck areas, are known as *unproductive*; that is, they will not produce normal growth of lettuce or spinach or certain other vegetables. It has not been proved definitely whether the lack of crop production in such soils is due to some toxin or to the absence of a food element. But it is now known that if blue vitriol is broadcast over such areas at the rate of 100 to 200 pounds an acre, in some cases production at once returns to normal. In fact such small amounts of copper as are contained in copper-lime dust applied on a preceding vegetable crop is sufficient to produce a similar change. Not all unproductive soils react favorably to copper treatment; yet wherever they are found, the treatment should be tried.

Copper carbonate is a coarsely or finely ground material that is almost wholly insoluble in water. One pound of this is stirred into 25 gallons of water and applied either right after the seed is sown, at the rate of 2 pints for each square foot or one pint for each 5 feet is poured along the seedling row after the plants are up. The mixture is not harmful to foliage, consequently no great care needs to be exercised when treating the young plants. When an excess amount of the copper carbonate is applied, the plants may be somewhat stunted in growth. More than one application can be made if it is found necessary. This form of copper will remain in the soil for a long while as a protection to the plants while they grow, but it has the drawback that it does not always control Rhizoctonia. It may be used also as a dust by raking it into the top layer of soil. The same amount is required as when applied in water, namely 1 pound to each 100 square feet of bed surface. Unfortunately the dust is injurious to the linings of the throat and nostrils, so that if much of it is handled, the air becomes filled with floating copper and a mask is necessary for protection.

Instead of copper carbonate, 20–80 copper-lime dust is sometimes recommended. It seldom is used, however, since the addition of lime is of no great value except when it is desirable to change the alkalinity of the soil. It has been used in such few experiments in America that no definite recommendations in regard to the amounts to apply on the respective crops have been offered. In England, Bewley suggests that 10–90 dust of this type is beneficial when mixed with the soil at the rate of 3 ounces for each 4 square feet.

Before potato spraying became a general practice years ago, the soil was sprayed heavily with bordeaux mixture, a suspension made of blue vitriol and lime in water, for the control of tuber rot. It was soon found that it was more profitable to spray the vines than the soil. Since then, however, bordeaux mixture, 4–4–50 or 5–5–50, frequently has been recommended as a fungicide for spraying the surface of the bed to stop growth

of fungi that cause damping-off. This mixture is simple to make, easy to apply, cheap in cost, and usually harmless to crops even when put on in large quantities. Furthermore, the part that clings to the leaves helps in controlling foliage diseases. On the other hand, the copper has almost no diffusion power in the soil, and thus is unable to spread outward or downward more than a slight fraction of an inch. This leaves large enough areas unprotected for fungi to gain a foothold and finally to penetrate the young seedlings. As is true of other copper compounds, bordeaux mixture is not toxic to all destructive organisms found in the soil, so that its use is limited. Some growers who have tried it praise it highly, therefore it would seem advisable to test it in any plant beds where a more thorough type of soil treatment is not possible.

In England, Bewley has obtained excellent results by using cheshunt mixture for the control of Phytophthora in the soil and for certain other fungi. This mixture is made by mixing thoroughly 2 ounces of finely ground copper sulfate with 11 ounces of finely ground ammonium carbonate. The mixture is then placed in a tightly stoppered bottle and left for at least twenty-four hours before being used. One ounce of the material is dissolved in a little hot water, after which enough cold water is added to make 2 gallons. The surface of the soil to be treated is made thoroughly wet with this solution. Apparently it does not injure plant foliage, so can be poured directly over the seedlings. In addition to its effect as a fungicide, no doubt it has some fertilizer value since the ammonia is composed partly of nitrogen.

The cheshunt mixture has not been used very widely in America, and therefore it cannot be recommended with absolute certainty under New York State conditions, but it is a promising method of treatment.

MERCURY COMPOUNDS

Mercury is very toxic to many fungi, and is especially effective in the control of diseases caused by Rhizoctonia. It is for this reason that it has come into general use for treating soil where damping-off is likely to be present. The mercury may come in many combinations, such as bichloride of mercury (corrosive sublimate) both as a powder and in tablet form, mercurous chloride (calomel), mercuric oxide, and a very great number of organic-mercury compounds which are patented and sold under trade names.

The chief advantages in the use of mercury are that it kills many kinds of fungi quickly, is easy to apply, remains active for a long enough time to protect plants during short dangerous periods, and is fairly cheap in price.

Its principal disadvantages are that in some soils it injures plant growth,

that it will not affect nematodes, that it is extremely poisonous if taken into the human system, and that some of the compounds are so heavy that if mixed with water they settle rapidly to the bottom of the container if not stirred repeatedly.

Corrosive sublimate is now used generally on cabbage, cauliflower, and brussels-sprouts beds to control damping-off, wire-stem, club-root, and maggots. One ounce is dissolved in a little hot water, and then enough cold water is added to make 10 to 15 gallons, depending upon the crop to be protected and the organism to be combated. If the crop is cabbage and the maggot is to be controlled, a concentration of 1 ounce to 10 gallons is applied; if Rhizoctonia is to be controlled on the same crop, 1 ounce to 12 gallons is strong enough; and if cauliflower or brussels sprouts are to be treated, 1 ounce in 15 gallons is as concentrated as can safely be applied. The liquid is poured along the row in such a manner that the soil is made wet about the base of each plant. When the plants are very small, 1 gallon of the solution will treat 40 feet of row, but when they are larger, 2 gallons are required for the same distance. Cabbage is resistant enough to injury so that no great pains need to be taken to avoid wetting the leaves with the liquid, but cauliflower foliage is very susceptible, and care must be taken not to pour it directly over the leaves.

In small beds, especially in hotbeds, the solution can be applied with a wooden pail or earthen jar and a teacup. In larger beds, it is necessary to have a more rapid method. In some cases a sprinkling can may be lined with melted paraffin, so that the mercury will not react on the metal, and a cork with a V-shaped cut placed in the spout. With a little experimenting, the cut can be made just large enough to permit the flow necessary when the operator is walking slowly along the row. In extended seedbeds it may be necessary to arrange a wheelbarrow with a small barrel and a gravity or siphon pipe or rubber hose so directed that the stream will meet the soil at the base of the plants in the row. A fish-tail opening at the end of the hose sometimes is preferable. Other apparatus can be designed readily by the operator.

The number of applications to make on each bed varies from year to year. If only maggots are to be controlled, one or two applications may be sufficient. But when diseases are included, from three to five treatments usually are necessary. The first one is made as soon as the plants are up and then the treatment is repeated at weekly intervals.

Other vegetable seedlings, such as peppers, tomatoes, muskmelons, and eggplant, may in some localities be treated with corrosive sublimate in exactly the same manner as recommended for cauliflower. In other places, however, the plants may be injured. Consequently, it is suggested that where the grower desires to use corrosive sublimate or any of the other

mercury compounds on these crops that he test the material on a small area at first to see whether his conditions will permit the use of mercury without injury to the seedlings.

Very good results also have been obtained with these and organic-mercury compounds on forest-nursery seedlings where an application was made when the seed was first sown. From 4 to 6 ounces of the corrosive sublimate or from 3½ to5½ ounces of calomel was used (either dry or in liquid) for each 1000 square feet of bed. The others are used according to the directions on the label.

The organic-mercury compounds, of which there are a large number on the market at the present time, are recommended wherever the other mercury compounds may be used. Some of them are applied to the seedbed immediately after sowing the seed, and some are used after the vegetable plants are up, in a manner similar to that recommended for corrosive sublimate. In many places these compounds have given satisfactory results. They should be applied according to the directions printed on the containter.

These organic compounds may cause injury under certain conditions as is true of other mercury combinations. They are relatively high in price. But the greatest objection seems to be that the materials under the various trade names are changed in composition so rapidly that the research man cannot test them promptly when new combinations or new brands are manufactured. Consequently, some of these chemicals are sold on the strength of the manufacturer's word, with too little experimental evidence back of it. If a grower has once used a brand and found it satisfactory, there is no reason why he should not continue its use. In the meanwhile he should test each new mixture before buying large quantities.

On many lawns and golf greens, the grass is killed in spots by Rhizoctonia. The disease is known as *large brown-patch* or as *small brown-patch,* depending upon the species of the fungus present and the resulting size of the injured area. It has been found in recent years that most any of the mercury compounds will control the disease if sprayed over the lawn by means of an ordinary fungicide sprayer. There is some variation in the recommendations as regards the concentration of the material and the amount to apply. Discussions of these recommendations appear in the recent volumes of the *United States Golf Association Bulletin* (Green Section). In general, 1.5 ounces of calomel, corrosive sublimate, or mercuric oxide is required for a light dosage on 6000 square feet of lawn. When heavier dosages are desirable, 3 ounces is applied to this sized area. The chemicals may be mixed in 50 gallons of water and sprayed over the green, or the calomel and oxide can be mixed with slightly dampened sand as a carrier and dusted over the area. If organic-mercury compounds are

used, such as Semesan or Uspulun, 1 pound of the material is placed in 50 gallons of water and sprayed over 6000 square feet of the green.

No matter what form of mercury is applied certain weather conditions may follow and cause a slight yellowing of the otherwise healthy grass. For this reason lighter dosages are recommended during the middle of the summer.

The number of applications for the control of brown-patch is variable. If the weather continues warm and humid, an application every five to six days may be necessary. In other seasons when the rainfall is scant, and the greens are exposed enough to air currents so that dew will dry quickly, one application a month may be sufficient.

MISCELLANEOUS COMPOUNDS

Aluminum sulfate

Aluminum sulfate has not been tried generally in soil treatments for the control of damping-off, but where it was applied to beds in tree nurseries it gave excellent results. If further experiments prove it to be as valuable as preliminary work would seem to indicate, it should be a rather popular soil treating chemical. It is cheap in price, not dangerous to handle, and is easily applied either dry or in liquid form. No definite recommendations can be made in regard to the amounts to apply, but from 16 to 20 pounds for each 1000 square feet of bed surface seems to be approximately correct. This material can be placed into enough water to wet the soil thoroughly and applied immediately after the seeds are planted or the material can be applied dry and raked into the soil just before planting the seed.

Bleaching powder

Bleaching powder (calcium hypochlorite) has been tested in this country with only moderate success, but in England it has been used with favorable results in treating soil for the control of the violet-colored Rhizoctonia. Two ounces of the material was raked into each square yard of bed surface about two weeks before the crop was planted. The principal crop tested was carrots. Larger dosages caused injury. It has not been tried on enough crops nor with enough parasites to make any definite recommendations.

Carbolic acid

Carbolic acid is mentioned often in plant-disease literature, although no successful experiments seem to have been conducted in its use for soil treatment. It apparently causes very little injury to fungi or insects. It is said to decrease the number of nematodes somewhat if the application is made in the fall and the crop planted the following spring. According

to data collected in England this chemical increases the yield of some crops even when diseases are not present.

Potassium permanganate

Potassium permanganate has been applied to the soil for the control of damping-off in England, and especially in Scotland where it seems to be a popular remedy. The strength suggested is 1 ounce of the chemical in 4 gallons of water, and the soil is wet down as soon as there is danger of the disease. It is not supposed to be injurious to growing plants. In America the chemical has been found to have only very slight fungicidal value, although a detailed study of its action on soil organisms seems to be lacking.

Electric lights

Electric lights have been used in Massachusetts for combating damping-off. Mazda lamps of 200-watt power are suspended 2 feet above the seedlings. A dome reflector is used to concentrate the light in such a manner that about two hundred seedlings can be grown under one light. The lights are turned on as soon as the seed is planted, and turned off only on bright sunny days. The control of the damping-off is due probably to the drying of the atmosphere, the heating of the surface layer of soil, and the hastening of the seedling growth. If the soil is too fertile, the plants subjected to the artificial light may become spindly. This unfavorable condition is avoided by mixing half sand and half garden soil.

Many other materials have been tested in soil treatments, some of which may later prove very beneficial where soil-borne organisims are to be combated.

Problems Come in Pairs

PROBLEMS never come singly; they are at least double,—and generally in large bunches.

For example, you who read this booklet probably need to know what will make a plant develop, and also need to know how to keep plant diseases from developing.

The Cornell University Agricultural Experiment Station and the New York State College of Agriculture have other pamphlets which will serve you. Some of these are:

Bacterial canker of tomatoes (E 170) *Jones and Pederson*

Combating diseases of vegetables (E 171) *Chupp*

Commercial varieties of vegetables for New York State (E 176) *Schneck*

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